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AIR PUBLICATION 44.

ROYAL AIR FORCE

NOTES ON AIR PILOTAGE

The following Notes on Air Pilotage are promulgated for the information and guidance of all concerned.

By Command of the Air Council.

W F Nicholson

AIR MINISTRY,
July, 1920.

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CONTENTS.

INTRODUCTION.

In marine navigation, pilotage is said to be the art of conducting a ship when in sight of land, or in soundings, and navigation, the art of conducting a ship from port to port when out of sight of land.

Air pilotage corresponds in many respects to pilotage of the sea, in that it is the method employed to conduct an aircraft from place to place when over or in sight of land, or over short distances of sea.

The art of air pilotage is therefore the ability to pilot an aircraft safely and accurately from one point to another by dead reckoning, map reading and the use of suitable instruments.

A thorough knowledge of air pilotage is the basic foundation for the study of air navigation, which, with the advance of the science of air travel, is becoming of vastly increased importance.

Although a precise knowledge of map reading is essential, it must be remembered that a map is only of use when the ground it represents is visible, and efficiency in air pilotage is contingent on the ability to fly above or in mist and clouds, to fly for short distances up to 100 miles over the sea, and to fly at night. Primary importance is therefore attached to an exhaustive knowledge of the magnetic compass and of the instruments complementary to it.

Air pilotage, properly understood and applied, will ensure that the shortest track between any two places is covered by the aircraft, whatever weather conditions prevail.

While a simple preliminary calculation based on data determined by actual experiment will allow the pilot to fly in calm air above storms and fog on a direct course to his destination.

Finally it must be remembered that dead reckoning is of the greatest importance in navigation by directional wireless, or by sextant sights of heavenly bodies, it being necessary in all forms of navigation to be able to give the estimated or dead reckoning position of the craft at any given moment.

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CHAPTER I.

MAPS.—SECTION I.

In considering the science of air pilotage in detail, the first section to be dealt with is map and chart reading, which forms an important part of the training of the air pilot, and is the one to which he will naturally first turn to guide him in his preliminary flights across country.

It is essential that a thorough grasp of map and chart reading be gained from the outset, so that observations for position or direction may be quickly plotted, the conventional signs understood, and the type of country represented readily recognised from the air.

It is clear, however, that a map is only useful when the land which it represents is visible and well marked, and that in fog or cloud or when flying over the sea or featureless country, such as desert, etc., direct comparison between the map and the ground fails and the pilot can only use it to plot the course by means of instruments.

A Map.—A map is a representation on a plane surface of a portion of the Earth's surface, showing a greater proportion of land than water.

The unit of measurement is the statute mile, which is 5,280 ft.

Projection.—A projection is a representation of a figure on a plane surface formed by the intersection of that plane by lines, drawn to the observer's eye, to every visible point of the figure.

There are various forms of projection which will not be described in detail herein, and the pilot may confine his knowledge to the fact that most Admiralty charts are on the projection of Mercator and Ordnance Survey Maps on Cassini's or the International Polyconic.

Scale.—Scale is the proportion between linear distance on the ground and the representation of that distance on the map.

It may be denoted in three ways, all of which are usually shown on the map :—

(*a*) By a representative fraction known as R.F.

(*b*) By words, *e.g.* one inch to one mile.

(*c*) By a graduated scale line.

The numerator of the representative fraction always equals " one " and both the numerator and the denominator must be of the same character, *i.e.* both inches, feet, yards, cms., etc. In the R.F. the numerator always bears the same proportion to the denominator the unit distance on the map bears to the unit distance on the ground.

For example R.F. $\frac{1}{63{,}360}$ means 1 inch on the map equals 63,360 in. or one mile on the ground. The scale being therefore one inch to one mile.

The standard unit of Great Britain is the inch.

The standard unit of Continental maps is the cm.

The following examples will help to show how the scale of a map may be calculated when the R.F. only is given :—

(1) To find how many statute miles to the inch—
Divide the denominator by 63,360:

$$i.e.\ \text{R.F.} = \frac{1}{80{,}000} \therefore \frac{80{,}000}{63{,}360} = 1{,}263 \text{ miles to one inch.}$$

(2) To find how many inches to the statute mile :—
Divide 63,360 by the denominator of the R.F.:

$$i.e.\ \text{R.F.} = \frac{1}{80{,}000} \therefore \frac{63{,}360}{80{,}000} = \cdot 792 \text{ inch to one mile.}$$

It is useful to note that the Ordnance Survey Maps commonly used in the air are drawn to the following scales :—

2 miles to 1 inch	$\frac{1}{26,720}$
4 miles to 1 inch	$\frac{1}{253,440}$
10 miles to 1 inch	$\frac{1}{633,600}$
16 miles to 1 inch	$\frac{1}{1,000,000}$

Continental scales are usually :—

$$\frac{1}{1,000,000} \qquad \frac{1}{250,000} \qquad \frac{1}{100,000}$$

on the map representing kilometres on the ground.

Relief.—Differences in the altitude of the country are represented on the map by :—

(*a*) Contour lines.

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Page 5, line 8, for $\frac{1}{250,000}$ substitute $\frac{1}{200,000}$

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The distance on the ground, *i.e.* in plan between any two adjacent contours, is termed the horizontal equivalent (H.E.) and varies with the slope of the gradient.

The height of each contour is usually given in feet above sea level, or if coloured, a scale of height is shown at the edge of the map, stating the height above sea level which each shade represents.

Map Reading.—Map reading is the art of grasping the topographical features, and the general appearance of a portion of the earth's surface, by the inspection of a map representing it.

In air pilotage it further consists of being able to recognise the features of the country as seen from the air, thus enabling the position of the air craft relative to the ground beneath it to be fixed.

Before attempting to read a map, it must be set, *i.e.* the N. point must be fixed. This is best done by aligning the magnetic meridian with a compass needle (allowance being made for deviation and variation if necessary). Some maps have the magnetic meridians printed in red lines across the face, while others including the majority of ordnance maps are constructed so that their sides point true north and south. Having set the map, the next thing to do, before starting on a cross-country flight, is to lay off the course between the point of departure and the objective. This is done by joining them by a straight line. Now, since this is the track to be made good, the features of the ground between the two points must be examined carefully and memorised as far as possible.

Objects which are most useful to the air pilot are railways, rivers, towns, villages, churches, tall towers or chimneys, large woods, etc.

Any striking object, in fact, which appears on or close to the proposed route should be carefully noted.

It is also of particular importance that the contours of the country over which the route passes be carefully studied, so that the aircraft may be piloted at a sufficient height to pass well over any range of hills or mountains.

This is of special importance in misty or cloudy weather, and a point which must also not be overlooked is that the altimeter or height recorder will show the height of the aircraft above the point of departure, and not necessarily above the point of arrival or any places on the route.

Every pilot should be able to read a map from any point of view, and he is far less liable to make mistakes if he sets his map in the air so that the track marked on the map is kept parallel to the course made good.

Before starting on a cross-country flight, the estimated time of passing over various prominent landmarks on the course should be noted on the map against each object, so that, when flying, the compass course can be checked by referring to these objects and observing if the actual course made good brings the aircraft over them at the estimated times. Should the pilot meet with fog or low clouds he will then be in a position to continue the flight by compass in full confidence that he is maintaining his correct course.

CHARTS.—SECTION II.

A chart is a representation of a portion of the surface of the globe showing a much larger proportion of water to land, and is adapted to the requirements of the mariner.

The unit of measurement is the nautical mile, which is 6,080 ft.

Measurement on a Chart.—Positions on a chart are fixed by reference to their latitude and longitude, and surface measurement is made in degrees of latitude, each degree containing 60′ of arc, one minute of arc being equal to 6,080 ft. or one nautical mile.

A knot is a rate of speed. It is the rate of one sea mile per hour, and is roughly $1\frac{1}{8}$ miles.

A cable is appioximately 200 yd. in length, 10 cables being equal to one sea mile.

The parallels of latitude are equally divided into degrees of longitude, which, however, vary in length according to the latitude in which they are measured.

The length of 1° of longitude in latitude 0°, that is on the Equator, which is the great circle dividing the Earth into the northern and southern hemispheres, is 60 nautical miles, and at the Pole, latitude 90°, it is nothing.

In the latitude of Greenwich, 51° 31′, the length of 1° of longitude is 38 nautical miles.

From this it will be seen that longitude is not distance, but an angular division of 360°, and therefore in measuring distances on a chart the scale of latitude must always be used.

Types of Charts.—Admiralty charts are of four kinds :—

(1) World charts.
(2) Ocean charts.
(3) General charts.
(4) Plans.

Numbers 1, 2 and 3 are drawn on Mercator's projection and No. 4 on a plane projection.

In Mercator's projection, all meridians are drawn as straight lines at right angles to the parallels of latitude, which are also shown as parallel straight lines.

Scale.—Every chart has two scales.

(*a*) A varying one for latitude and distance.

(*b*) A constant one for longitude.

The scale of latitude and distance will be found at the sides of the chart, and the scale of longitude at the top and bottom.

To find distance on a chart—

Measure with the dividers the distance between the two places, and transfer this distance to the graduations at the side of the chart as nearly opposite the places as possible.

It is very important that the distance should be measured opposite the two places, since as the scale of latitude is increasing towards the north, distances measured to the north or south of the two places will be incorrect.

If the places have the same or nearly the same latitude, take half the space between them, apply it to the graduated meridian above and below the parallel on which the places are situated. The difference between the degrees of the extreme points converted to minutes will be the distance required in nautical miles.

Latitude and longitude can be found or laid off on a chart with a parallel ruler, or a Douglas protractor.

To Read a Chart.—The key to the chart is the title, and this should be carefully read through first. From this the locality covered, date of survey, abbreviations for lights, and buoys, nature of sea bottom, soundings, tides, etc., will be found.

The date of the chart will be found on the bottom centre of the chart and in the bottom left-hand corner the dates in Roman numerals of any small corrections made since the chart was published. The coastline and all channels at sea or in river mouths are indicated by lighthouses, lightships or buoys, each of which show a characteristic mark and light.

These lights are just as useful to the air pilot as to the sea pilot, and in all cases where the nature of his duty takes the pilot over the sea or along the coast, use should be made of these distinctive points, just as of a railway or river when flying inland. When piloting an aircraft by night, great assistance is given by the lights shown by lighthouses, etc., and beacons and aerial lighthouses are being erected on the principal air routes, as additional guides to the night pilot.

Characteristics of Lighthouses, etc.—In English waters, all light vessels are painted red, with the name indicated clearly on the hull in white letters.

In Irish waters light vessels are painted black.

All light vessels carry further a day or top mark, which will be found in the Admiralty light lists.

Lighthouses are distinguished by various markings, such as a white tower with a black band halfway up, or a black tower with two white bands, etc.

Before starting on a flight, a part or all of which will be over the coast or the sea, the pilot should study the charts of the areas over which his course will take him, and note just as on a map the lighthouses, or vessels, etc., which will be passed *en route*, and the estimated times at which the aircraft should pass over them.

If the flight should be at night, the lights shown by the various lighthouses, etc., to be passed should be carefully noted, together with the

range from which they are visible. This latter information is always given on the chart by the side of the light, thus, Lt.Gp.Fl. (3) ev. 30 sec. vis. 10 m. (178) indicates a lighthouse, 178 ft. high, showing a group of three flashes every 30 seconds, visible for 10 miles.

It is unnecessary to set a chart as must be done with a map.

All Admiralty charts have several compass roses printed on the surface, showing the variation, and true and magnetic points, so that by means of a pair of parallel rulers the required course can be readily laid off.

Moreover, in nearly all cases, Admiralty charts are constructed pointing true north and south.

A full explanation of all the signs on charts relating to lighthouses, light vessels, etc., and also all the different lights exhibited is given in the Admiralty Light List and an explanation of the conventional signs used in the Admiralty Manual of Navigation.

CHAPTER II.

THE MAGNETIC COMPASS.

The next step in the study of air pilotage is the magnetic compass.

It is proposed to treat of it in this chapter essentially from the flying point of view, and only to touch briefly on the general principles, which are well known, and on which many text-books already exist.

The Magnetic Compass.—The magnetic compass is an instrument that indicates direction or bearing, and in aircraft may be used—

(1) To steer in any required direction, or from one place to another.
(2) To ascertain the direction or bearing of any visible object from the aircraft, whether in the air or on the ground.
(3) To fix the position of the aircraft by taking cross or running bearings of visible objects.
(4) In the absence of other instruments, to determine the drift of the aircraft and the direction of the wind.
(5) To indicate the course of ships and surface craft on the route of the aircraft.
(6) As an indication of turning on an aircraft, and a measure of the extent of the turn in the absence of other indicators.

Since the controlling force of the compass needle is the magnetism of the earth, it will always lie in the magnetic meridian, with its north or red end pointing to the magnetic north, if undisturbed by outside forces.

The magnetic needle or system of needles in a compass are freely suspended and attached to a card graduated in degrees, the whole being suspended in a non-magnetic bowl filled with liquid, the function of which is to damp vibration.

Lubber's Point or Lubber Line.—In every compass used for the purpose of directing an aircraft from one place to another, the direction of the craft's head is shown by a small metal horizontal pointer fixed to the compass bowl, or a vertical line painted inside the bowl called the lubber line and the lubber's point respectively.

In fitting the compass into the aircraft, it should be placed so that the lubber line or lubber's point corresponds exactly with the fore-and-aft axis of the craft, or is in a line parallel with it.

The course steered by an aircraft is read at the point where the lubber line cuts the card.

When the direction of the aircraft's head is changed, the card and magnetic needles remain still, and the lubber line revolves about the card and records the angle through which it has moved, thus giving the angle between the fore-and-aft line of the aircraft and the magnetic meridian, which is considered as zero.

Marking of the Compass Card.—The compass card is considered to be divided up into 360 degrees (a circle containing 360° of arc); each degree is then sub-divided into 60 minutes (60′), and each minute into 60 seconds (60″).

Aero compasses are usually marked every 10°, and the divisions are numbered from north through east, south and west in a clockwise direction from 0° to 360°.

In most aero compasses the card is necessarily small, and the figures are therefore shown without the 0. Thus 20° is marked 2, 180° 18, etc.

In every card there are four quadrants, each containing 90°, and each quadrant is again divided into eight points, making 32 in all (note aero compasses are not marked in points).

The cardinal points are N., S., E. and W.

The quadrantal points are N.E., S.E., S.W. and N.W.

The reciprocal of any point is found by changing the letters N. for S., E. for W., and *vice versa, e.g.*, N.N.E. reciprocal is S.S.W.; S.W. by S. reciprocal N.E. by N.

The compass course may either be stated in degrees, *i.e.*, 90°, 135°, or by reference to the cardinal points, *i.e.*, N. 30 E., N. 45 W., S. 22 E., or S. 10 W. In stating the course in this latter method it must be remembered that the course must always be given with reference to either the N. or S. point, *i.e.*, from N. 1° to 90° E. or W.; from S. 1° to 90° E. or W.

Practical Flying by and use of the Compass in the Air.—On page 9 the various uses to which a magnetic compass may be put were briefly described.

These sections will now be dealt with in detail.

1. The first and primary function of the magnetic compass is to indicate the direction in which the aircraft is travelling. When carrying out a cross-country flight the compass course to be steered must always be plotted on the map or chart before starting.

Since the magnetic North Pole is subject to variation, charts and maps are always constructed on true bearings, and therefore the compass course worked out should always be the true course, allowance being made for the usual errors of variation and deviation, which will be explained in the following chapter.

Having plotted the true compass course to steer, the pilot, as soon as sufficient height has been obtained, should set the aircraft's head so that the lubber line cuts the compass card on the required course. By steadily keeping the craft's head on this course, the destination will presently be reached, always providing due allowance has been made for the effect of the wind on the machine.

2. During the flight the pilot may wish to report the position of some object passed, or get a rough check on his own position. This may be done by taking a bearing of some objects selected and noting the time at which this bearing is taken and the estimated position of the aircraft.

The observer is provided with a special instrument called a bearing plate for this purpose, but in most cases the pilot must rely on his compass.

A number of aero compasses are provided with a bearing ring having a sighting device on it, and by sliding this round the compass and sighting the object required, the bearing can be read off.

If no bearing ring is provided, a rough bearing can be got by sighting the object across the compass and noting the reading.

3. During a long flight the position of the aircraft should be constantly checked to see that the desired track over the ground is being made good.

The observer again can use the bearing plate, but the pilot can get a rough idea of his position by sighting on two objects some distance apart, getting the bearing of each, and noting on his map the position where the two lines intersect.

4. Before starting on a flight the estimated strength of the wind at the height at which it is proposed to fly must be obtained, but it is very necessary when actually on this flight to constantly check the direction of the wind, by estimating the drift of the aircraft.

A drift indicator is provided, but the pilot can arrive at a rough estimate of the wind's direction by steering the craft on different courses until no drift is apparent and noting the reading of the compass.

The course which has to be steered to reach the point of arrival being known, a simple calculation will give the number of degrees the aircraft is drifting.

5. When carrying out reconnaissances over the sea, it is often necessary to report on the movements of ships, which will necessitate stating what course they are steering. This can easily be ascertained by steering the aircraft straight along the fore-and-aft line of the ship and noting the compass reading.

6. When carrying out long flights or reconnaissances, it is often necessary to alter the course of the aircraft; also, whenever a turn is made in the air, it is always useful to know the extent of this turn.

Special instruments are now generally provided for this purpose, but in their absence, or in case they are not working, the compass will always give the information required. As the aircraft is turned, the lubber line moves round the face of the compass, and as soon as the turn is complete and the craft steadied on its new course, the number of degrees through which the lubber line has moved from the former position can quickly be read.

In clouds or misty weather, by watching the movements of the lubber line, it can at once be seen if the aircraft is turning.

The question of taking bearings has only been roughly discussed, but a full explanation of the various methods is given in Chapter 7.

There remain now a few practical hints on flying by compass.

To steer a steady compass course in the air is not difficult and requires practice more than anything else, but there are a few points which require notice :—

1. It must be remembered that the compass card and needles remain stationary, unless affected by a violent disturbance, and it is the lubber line which actually moves round the card.

In clouds, or when flying at night, the compass card will often appear to be rotating, when it is actually the machine turning about the card. This fact is well illustrated in the case of a passenger in the compartment of a railway carriage, with the sun on one side of the train. So long as the track is straight, the sun will appear to be stationary for a short space of time, but as soon as the train travels round a curve of large radius, the only sense of any change of direction apparent to the passenger will be the movement of the shadows thrown by the sun across the compartment.

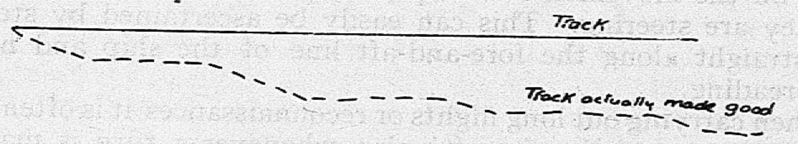
2. Due to bumps or inaccurate flying, the aircraft may be caused to deviate from the correct course, and in counteracting this, care must be taken not to attempt to make any sudden alteration of the craftshead.

The pilot must be steady on the rudder, as the effect of sudden alterations of direction one way or another may cause the compass card actually to swing, in which case the compass will be useless.

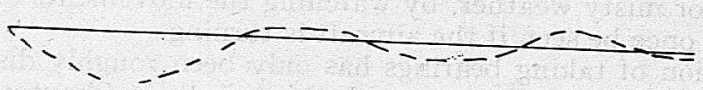
If, as may happen, when flying at night or in clouds, the compass appears to be rotating, it is an indication that the aircraft is turning rapidly. This should at once be corrected, not by attempting to " chase " the compass card by turning the machine sharply, but by first of all putting the controls neutral and steadying up the compass on the new course and then secondly by making a slow turn back to the original course.

If the aircraft has swung off its course to the extent of some 10 or 20 degrees, the pilot must remember that if he merely returns to his original

course, he will not be travelling on his real track, but on one parallel to it. This means that should the machine keep continually swinging away in the same direction, and the pilot just corrects by returning to the original course, he will be gradually edging away from his real track, and after some time will be some considerable distance from it, having made good a track as shown below.



This possible error is easily corrected, if the pilot when the machine has swung off to the left or right, instead of immediately altering to the original course, steers for a minute or so in the opposite direction to the swing off and then alters to the original course. In this way a track will be made good as follows :—



To illustrate this, take the following example :—

A pilot is steering east (90°). The machine swings off on to a course of 110° for one minute. To correct this the pilot alters course to 70° and after holding on this course for one minute, returns to his original course of 90°. The machine will now be very approximately on the correct course again.

There is one more error which a pilot must guard against, and that is parallax.

Parallax is an error caused by not sighting or reading a body from the correct position. The pilot, therefore, should be careful to read the compass from the same position, which should, if possible, be straight in front of him, and not read it by looking at it sideways. The error caused by this may not be large, but on a long flight is sufficient to matter.

Types of Aero Compasses.—There are at the present time about six magnetic compasses in general use in the Royal Air Force, and although a number of other types exist, it is not proposed to describe them, as they are either obsolete or obsolescent.

In describing a magnetic compass, the period of the compass is always referred to. By this is meant the time taken by the magnetic needle or needles to execute one complete oscillation after being disturbed from the magnetic meridian. The period is of considerable importance, as it is obviously very desirable that after a turn or other movement the card shall become steady quickly, and also that it will not be too easily disturbed.

Pattern 5/17.—This is a small "upright" compass, weighing about $2\frac{1}{2}$ lb. and having the following overall dimensions : $6\frac{1}{2}'' \times 5\frac{5}{8}'' \times 4''$. The card, which is upright, is carried on an inverted pivot without the support of a float, and is in the form of a ring sloping inwards from the upper edge at an angle of 30°. It is marked on both the inner and outer surfaces, the forward or direct readings being obtained against the inside graduations.

The graduations indicate every 10° and are numbered every 30°.

The outer surface of the card is black with the cardinal and quadrantal points painted on it in radium compound, for use in night piloting.

There is a lubber line at the back of the bowl for reading the inside of the card, and another on the face of the compass for reading the outside.

The face of the compass, which is of glass, is sloped back at an angle of 20° to facilitate reading the inside card. It should be noted that the front lubber line is very broad, and to get an accurate reading, the imaginary centre must be taken.

It has a quick period of about eight seconds and a very dead-beat card, consequently it settles down very quickly, but is not steady in bumpy weather.

The adjusting box is on top of the bowl.

R.A.F. Mark II.—This is a large upright compass, weighing approximately 4 lb. 10 oz. and measuring $9\frac{1}{2}'' \times 5\frac{1}{2}'' \times 5\frac{1}{2}''$. The card is upright and attached to a float, being suspended in a spherical bowl.

The card is marked every 10° and numbered every 20°, and is read from a lubber line at the back of the bowl.

It has a very long period of from 37 to 40 seconds, and is fairly steady in bumpy weather. Once disturbed, however, it takes some considerable time to settle down.

The adjusting box is cylindrical and contains tubes fixed on to the bottom of the compass.

R.A.F. Mark II.—Quick Period.—This is a modification of the above type, having a floatless upright card, marked every 10° and numbered every 30°. It has a period of about 12 seconds.

There is also a small adjusting box on the top of the bowl.

Pattern 253.—This is a large-sized horizontal compass designed for use in large aeroplanes and seaplanes. It weighs nearly 7 lb., is about $4\frac{3}{4}$ in. high and $7\frac{3}{4}$ in. in diameter.

The card is marked every 2°, and consequently much more accurate readings are possible. It is lettered every 10°. The period of the card is 25 seconds.

Pattern 256.—This is a large upright compass designed for the same purpose as Pattern 253. The card is marked on the front only, in degrees, and numbered every 30°. It has a period of 25 seconds.

This type has two windows, one in front and one behind, so that when the observer sits in front of the pilot he can read the compass. The weight is $9\frac{1}{4}$ lb.

The Aperiodic Compass.—This is the very latest pattern of compass so far designed and has many remarkable features.

It was designed by the late Lieutenant-Commander G. R. Colin Campbell, R.N., with a view to solving many of the existing errors, by making a compass with no period at all.

It has no card, but consists of a system of needles, attached to which are eight copper wires, radiating from the centre to the cardinal and quadrantal points, which act as damping vanes.

There is no lubber line, but across the face of the glass covering the bowl is a white line, with an arrow at one end. This represents the fore-and-aft line of the craft, and must be so placed when fitted in a machine. The compass consists of an outer verge ring, marked in degrees and numbered every 10°, which revolves about the centre, and carries a grid which covers the face of the compass. The compass is read by rotating

the grid lines until they are parallel to the red pointer attached to the needles, with the red arrow on the verge ring in line with the north end of the pointer.

The bearing is then read off from where the arrow on the fore-and-aft line cuts the verge ring.

To steer a course by this compass, the verge ring must first be set to the course required by rotating it until the given course is opposite the arrow of the fore-and-aft line, and then the machine's head is turned until the pointer is parallel to any grid line, with N. on N. With a little practise it is very simple to steer a course by this compass, which is remarkably steady and free from errors.

General Points on Aero Compasses.—All cards on aero compasses are immersed in liquid consisting generally of two parts of pure alcohol to three parts of distilled water, though some are filled entirely with pure alcohol. This has a steadying effect on the card, and tends to damp out vibration.

This mixture should not freeze above 12° Fahrenheit and any expansion or contraction of the liquid is counteracted by the provision of an expansion chamber.

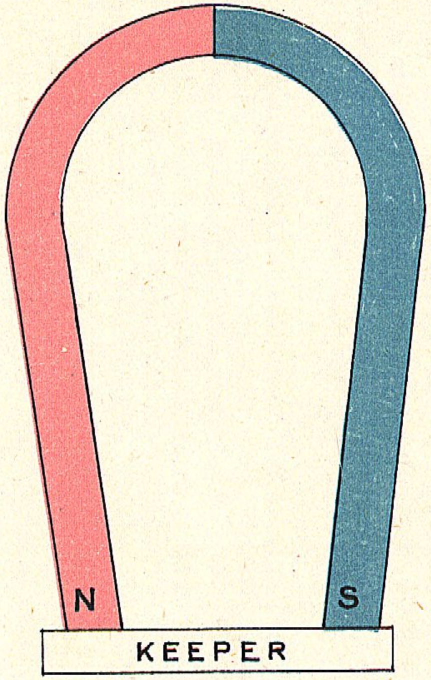
The bowl is attached to the outer ring or frame by means of anti-vibrational spring attachments, so that any moderate shocks which the machine experiences may not be transmitted to the compass.

The pivot of the compass is made of agate, and the cup in which it works of sapphire.

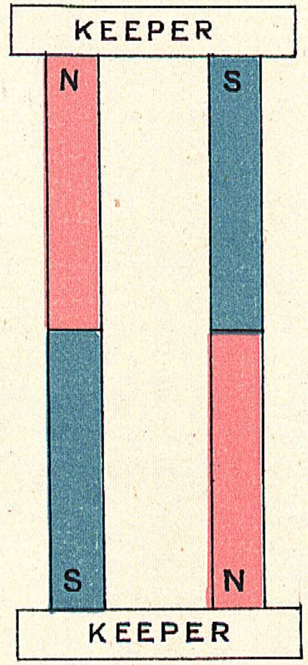
Removal of Bubbles from a Compass.—It is very important that any bubbles which may occur in the liquid in a compass be removed at once, otherwise currents are liable to be set up which may cause the card to swing and thus render the compass useless. To do this the compass must first be taken out of the machine, and then manipulated till the bubble is immediately below the filling plug. This plug is then removed and pure alcohol or, if this is not available, distilled water poured in till the bowl overflows (a fountain pen filler is very convenient for this work). The filling plug should now be screwed in again, and if the bubble has not then disappeared the operation must be repeated till it does.

The compass can then be carefully replaced in the machine. When performing this operation the bowl of the compass should be as cool as possible, so that the maximum amount of liquid may be introduced.

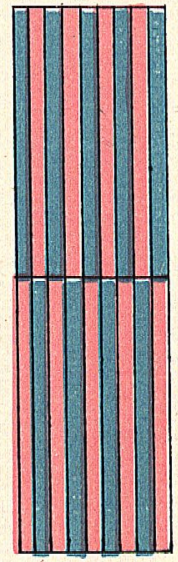
It is advisable that no repairs, other than that mentioned above, be attempted locally on any compass, and in all cases where readjustment, etc., is necessary, they should be returned to store for the required repairs.



Horse Shoe Magnet with Keeper.



Pair of Bar Magnets with Keepers.



Bundle of Magnetic Needles.

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CHAPTER III.

MAGNETISM AND COMPASS ERRORS AND THEIR ADJUSTMENT.

SECTION I—MAGNETISM.

It is clear that since the Earth's magnetism affects the needle of the compass, any other bodies which are magnets will also influence the compass needle if placed in close proximity to it.

It this chapter the effect of these various magnetic influences on the compass will be discussed and the methods of correcting them described.

It is necessary, however, that the fundamental principles of magnetism be understood, and these will be discussed first.

Definition of Magnetism.—Magnetism is a force existent all over the world, and is of such a nature that it exerts its influence on iron and steel, causing them to become magnetic, that is, to have the power of attracting materials similar to themselves.

There are two kinds of magnets—

(1) Natural.
(2) Artificial.

Natural magnets are found in the form of iron ore and lodestone, but are never used for compass work, since they vary greatly in strength.

Artificial magnets are pieces of iron or steel to which magnetic properties have been imparted by various methods.

Both are possessed of the same property, namely the power of attracting and holding iron.

Hard iron and steel are not easily magnetised, but when once this has been done, they retain it permanently.

Soft iron, on the other hand, becomes readily magnetised under the influence of even small magnetic forces, but it possesses no power of retaining its magnetism once these forces are removed.

Artificial magnets may be made in several ways, notably: (1) By contact with a natural magnet. (2) By contact with other artificial magnets. (3) By contact with an electric magnet. (4) By percussion. (5) By passing the bar into a coil through which an electric current is flowing.

Any part of a magnet contains more or less magnetism, but its greatest power is concentrated at two points near each extremity, these positions being known as the "Poles of the Magnet."

The Earth itself possesses the properties of a large magnet, following the same laws that an ordinary magnet does. Its poles, however, do not coincide with the geographical poles of the Earth, but are some distance from either, one being situated north-west of Hudson Bay, and the other in South Victoria Land.

Further they are not points like the geographical poles, but are areas of considerable extent.

Properties of Magnets.—A magnet suspended horizontally will always, if unaffected by local causes, lie with one end pointing to the magnetic North Pole.

This end is called the North Seeking or Red Pole of the magnet, the other end being called the South Seeking or Blue Pole.

A small, freely suspended magnetic needle, if passed over a bar magnet,

will be found to take up certain positions, and from these positions it is at once apparent that the needle is always pointing to one of the two poles of the magnet, which as previously explained are situated close to the end of the bar, and also that when directly over either of these poles it hangs vertically. Fig. II.

There is a point midway between the poles of the magnet where the influence exerted by one pole is exactly equal and opposite to the influence exerted by the other pole. This spot is called the neutral zone and over it the needle will lie horizontally.

It will further be observed that the Blue end or pole of the bar magnet attracts the Red end or pole of the needle, and *vice versa*.

This gives the important law, that "like polarities repel and unlike attract."

From this it will be seen that what is termed geographically the North Pole of the Earth contains Blue magnetism, and that Red magnetism exists at the South Pole.

Constitution of a Magnet.—A magnet actually consists of an infinitely large number of minute magnets, and the magnetism is distributed through the bar, although it appears to be local and situated near each end.

From this fact it will be seen that it is impossible to produce a magnet having only one pole, and no matter how often it may be broken each separate piece will still have a north and south pole.

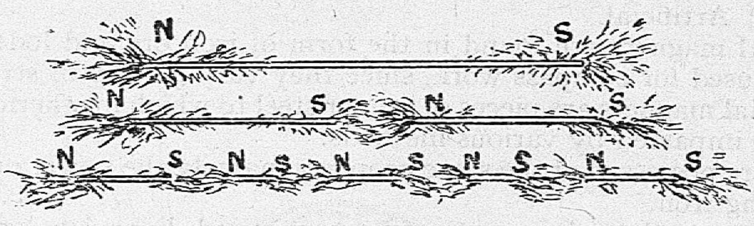


FIG. III.—MAGNETISED NEEDLE BROKEN UP.

Further Properties.—From the descriptions just given of a magnet it will be seen that it has considerably more effect on a magnetic needle when the latter is over one of its poles.

This gives the important rule that a magnet end on has twice as much effect on a magnetic needle or other object as when broad side on.

Further, a magnet acts most powerfully when its direction is at right angles to the north and south line of the disturbed needle.

Precautions to be taken with Magnets.—Magnets which it is desired to retain as such should never be heated, as their power is considerably reduced by any rise of temperature, and at a dull red heat they cease to be magnetic at all.

A magnet will have the same properties in any part of the world and in any direction in which it is placed, provided always that, if stowed with other magnets, the like poles are not together.

This gives another important rule.

When stowing magnets always pack them with the unlike poles together, *i.e.*, N. to S. If this is not done and they are stowed N. to N. or S. to S., since like poles repel, the magnetism of each will be weakened. There is another point which is also of importance. Magnetism always lies on the surface of a magnet, which must therefore be kept free from rust, as this again will reduce the power.

To avoid possible rusting, most magnets are painted half red and half blue.

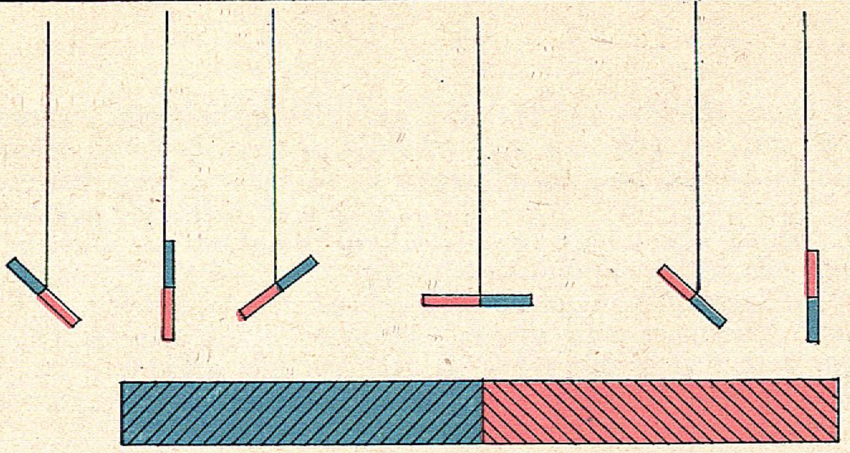


Fig. II.

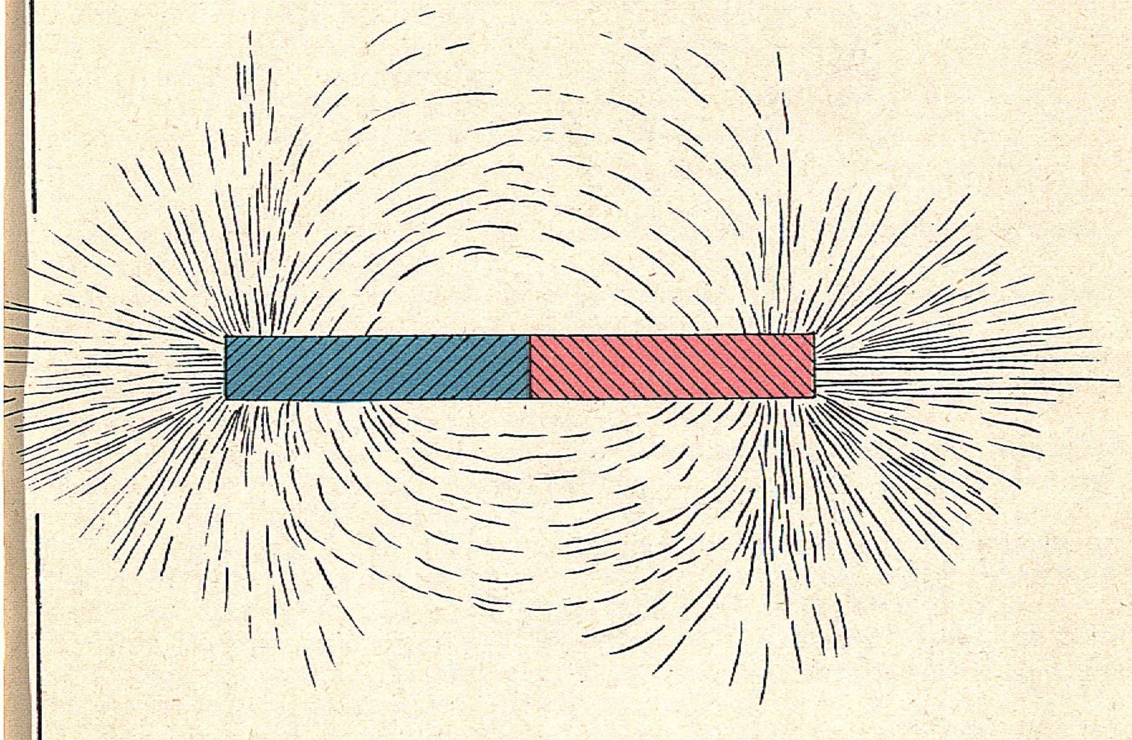
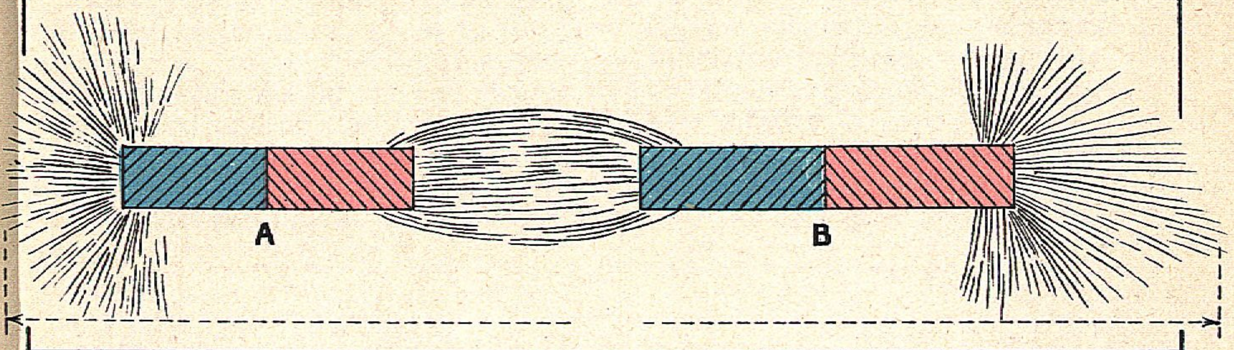


Fig. IV.



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Induced Magnetism.—It has been shown already that in magnets like poles repel and unlike poles attract, and the varying direction that a magnetic needle takes up if carried from end to end of a large fixed magnet has also been illustrated.

If this same magnetic needle is now taken and caused to oscillate at the same distance from and at different places on the fixed magnet, it will be found, by noting the time of each oscillation, that the movement is less when at the poles than in any other position. That is to say, when at the poles the oscillations are quicker and shorter, gradually getting longer and slower as the distance from the poles increases.

This gives the important fact that round every magnet there is a space in which its influence is felt, or rather in which a magnetic force exists. This force is strongest at the poles, getting weaker as the distance from them increases.

This space is called "the field of a magnet." (*See* Fig. IV).

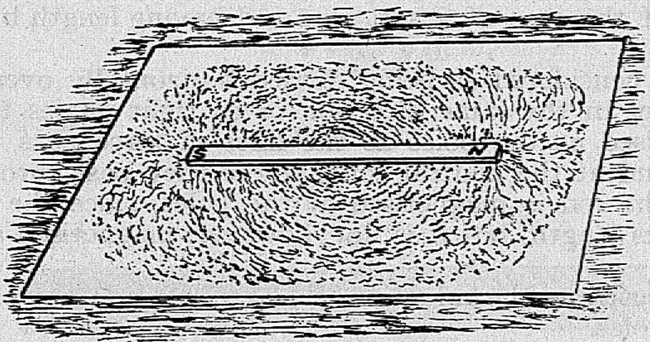


Fig. V.—Lines of Force.

Magnetic fields may be mapped out by means of a simple experiment with some fine iron filings.

A bar magnet is placed on a table covered with a thin sheet of glass, on top of which is placed a piece of paper.

If some fine iron filings are now dusted on to the paper they will be found to have arranged themselves as in Fig. V. (Note, by gently tapping the glass it will help the filings to arrange themselves.)

Each filing has become a temporary magnet and they have arranged themselves so that their red and blue poles are in opposition to the red and blue poles of the magnet.

The lines which the directions of the filings take up are known as "lines of force," and are considered as issuing out of the red pole, curving round in wider and wider circuits and finally entering the blue pole.

This experiment shows that iron filings will, if placed within the field of a magnet, become themselves magnetised, and they are said to have had magnetism "induced" in them.

This is a well-known rule and its application extends not only to iron filings but to any soft iron placed within the field of a magnet.

This rule is simply explained in the following words: "Magnetic induction is the name given to the power that a magnetic pole possesses of inducing, in a neighbouring piece of magnetic material, a magnetic condition such that at the end nearer to the magnetic pole unlike polarity is produced and at the more distant end like polarity."

Fig. VIII illustrates this principle. Let A be a magnet and B a soft iron ring. It will be found that A has induced magnetism in B, so that the red pole of B will be adjacent to the blue pole of A, or *vice versa*.

This is best explained by studying the lines of force. Lines of magnetic force always follow the track of least resistance and as the resistance in soft iron is less than that of the surrounding medium, because of its greater permeability, they all crowd into the soft iron and form a blue pole; a red pole being naturally formed where they emerge. If the soft iron bar is reversed end for end, the magnetism in it will be found to be also entirely reversed, the end which was formerly red becoming blue, and *vice versa*. If the bar is removed altogether it will at once cease to be magnetic, since soft iron retains its magnetism only while in the sphere of a magnetic influence.

This rule is of course subject to the influence of the Earth's magnetism, to which all materials capable of magnetisation are exposed.

In Fig. VI the effect of induction in soft iron rings is illustrated. These rings are the type used for correcting compasses by means of magnets.

The lines of force pass through the ring, forming red and blue poles as before.

In Fig. VII the case of a soft iron rod having length but no breadth is illustrated.

This rod is considered as being carried horizontally over the magnet, and lying either in the same direction or at right angles to it. (i) The rod is magnetised at the poles as the lines of force pass through it at right angles, and at the neutral zone, where they pass through its entire length. (ii) The rod is magnetised at the poles, since the lines of force pass through its length, but it is not, however, magnetised at the neutral zone.

Fig. VIII illustrates the induction of a large soft iron ring placed between the magnetic poles.

The lines of force from the red pole enter the ring, and following the line of least resistance, go round it, emerging again opposite the blue magnetic pole and *vice versa*.

Theoretically speaking, since all the lines go through the ring and none across it, a magnetic needle placed inside should remain unaffected. In practice, however, since no iron is entirely soft, always having a percentage of hard in it, a certain number of the lines of force do actually cross the ring, forming on the inside a red pole where they leave it and a blue where they re-enter again. It is interesting to note that in all steel machines these few lines of force form the external directive force, and as the greater number go through the iron, the interior directive force is very considerably greater.

Electric Installations.—Every electric machine possesses a magnetic field and a single electric wire has the power of directing a compass needle.

The magnetic lines of force produced round a wire through which an electric current is flowing, act at right angles to the direction of the current. If, however, two wires are laid together, having the current flowing in opposite directions, the effect of one will neutralize the other, consequently a compass needle will not be affected thereby.

This procedure is always carried out in the wiring of lighting sets. Magneto and switch wires are often laid singly and the compass should not be placed in proximity to them.

Dynamos, electric motors, etc., all have their magnetic fields, as have iron and steel, and the compass should be placed as far away from them as possible.

Terrestrial Magnetism.—The Earth itself being a great spherical magnet possesses the same properties as other magnets, so that, as mentioned

Fig. VI.

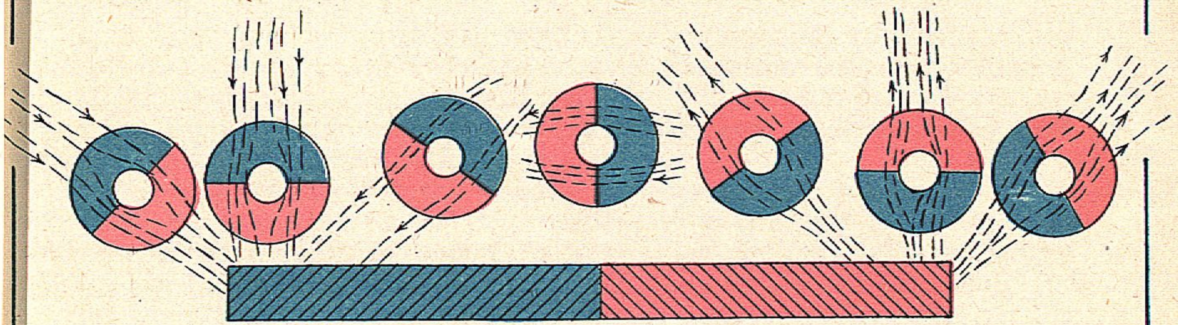


Fig. VII.

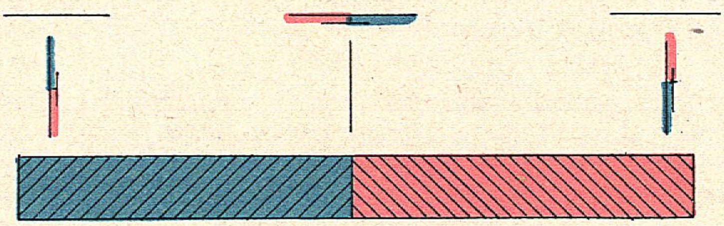
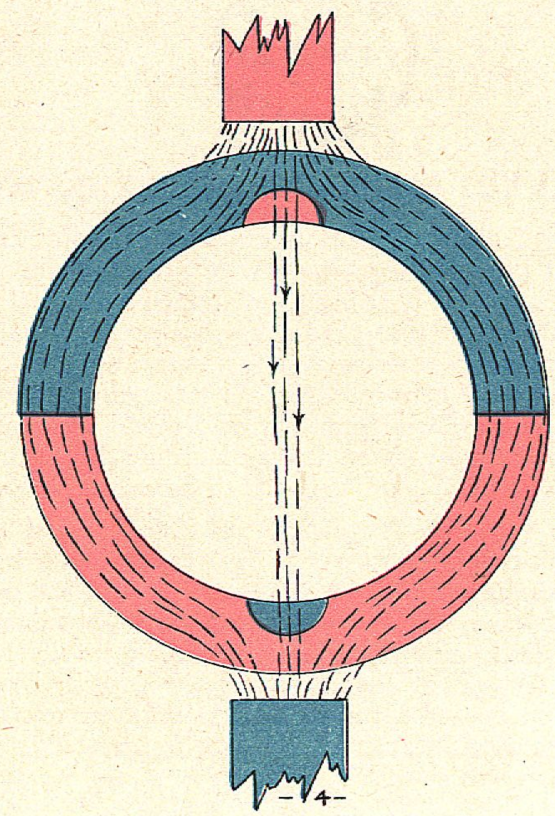


Fig. VIII.



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above, a freely suspended magnetised needle will, if undisturbed by local influences, lie with its North Seeking or red end in the direction of the Magnetic North, or *vice versa*.

Since the effect of the North Magnetic Pole is equal and opposite to that of the South Magnetic Pole, the effect of the former only is considered.

The magnetic influence of the North Magnetic Pole being permanent, its effect on a magnetic needle placed within any local magnetic field must always be reckoned with.

If the lines of force of the magnet in question are parallel to those of the Earth, no deflection of the needle will occur, but an increase or decrease of magnetic force, according to whether the two fields are acting together or in opposition.

On the other hand if the Earth's field is running at an angle to the magnet's field (under whose immediate influence the needle is), a deflection of the needle will occur.

The maximum deflection being apparent when the Earth's lines of force are at right angles to the needle.

The increase or decrease of the directive force can be found by deflecting the needle and timing the oscillations it makes; the longer the time of the swing, the less the directive force.

The value of the directive force varies inversely as the square of the times.

Local Magnetic Disturbance.—The term Local Magnetic Disturbance refers to magnetic forces outside the Aircraft, and not to the iron or steel in it. There are various areas on land, and under the sea, where eccentric magnetic conditions prevail, but these will not affect an aircraft, unless on the ground or the water on one of these areas.

The only magnetic influences met with in the air likely to upset the compass of an Aircraft are thunderstorms, or electrical discharges from clouds.

SECTION II.

COMPASS ERRORS AND THEIR CORRECTION.

The magnetic needle or system of needles in the compass will, if undisturbed by any outside forces, always point to the magnetic North. It has already been explained in Chapter I that all charts are based on true North because of the annual changes to which the magnetic North is subjected. For this reason it is necessary either (1) to convert the magnetic course to true, and so bring it into line with the chart. or (2) to convert all courses laid off on the map or chart from true to magnetic.

The first correction, then, that has to be dealt with is the conversion of either the magnetic course to the true one, or *vice versa*.

Variation.—The angle between the Magnetic North and the True North is known as the angle of Variation, the magnitude of which is known and can therefore be allowed for in taking compass readings. There is one magnetic meridian which must pass through both poles; consequently, if the compass is placed on this meridian the needle will point to True North and there will be no variation, but as the compass is moved away from this magnetic meridian the angle of Variation increases. The amount of this change is not constant and is found empirically for each locality.

The second law is governed by the fact that the angle of Variation is subject to annual change.

This is explained by the fact of the magnetic Poles not being fixed points on the Earth. They are, in fact, continually moving onward in unknown paths, and apparently complete a cycle in many hundreds of years. This movement normally is small, amounting to a few miles per annum.

The information that is required, therefore, before applying a correction for Variation is as follows :—

(i) Since the Variation is different in all parts of the world, the Variation of the area over which the Aircraft's course will lie must be known.

(ii) What annual change the Variation is subjected to in this area.

All this information is given on an Admiralty Chart, and often on a map, so that there is no difficulty in obtaining at once the correct variation for any required locality.

The magnetic compasses on a chart show the variation at a certain date and the amount of annual change, *e.g.*, Magnetic Variation (1912), 14° 56′ W., decreasing about 9′ annually, from which it is a simple matter to calculate the variation for the current year.

Having thus obtained the correct angle of Variation, it can now be applied to the magnetic course to get the true course, or *vice versa*.

The rule for this is as follows :—

(1) **The Variation is Westerly.**

The True Course = The Magnetic Course minus Variation.

(2) **The Variation is Easterly.**

The True Course = The Magnetic Course plus Variation.

It is important to remember that since the projection of all maps and charts is based on True North, the angle of Variation must always be allowed for when converting a true course or bearing into a magnetic one.

To obtain the magnetic course from the true course the above rules are reversed.

(i) **Variation West.**

Magnetic Course = True Course plus Variation.

(ii) **Variation East.**

Magnetic Course = True Course minus Variation.

It will thus be seen that the correction of a magnetic compass for Variation is a very simple matter involving only a small addition or subtraction sum.

The following examples should make the application of Variation quite clear.

(1) The True Bearing of A from B is 90°, and Variation is given as 15° 20′ W. in 1912, increasing 6′ annually.

(*a*) Variation in 1920 will be $15° 20' + 48'$ $(8 \times 6') = 16° 8'$.

(*b*) Magnetic Bearing of A from B will be $90° + 16° 8'$ (Variation is added because it is West) $=106° 8'$.

(2) The True Bearing of A from B is 120°, and Variation is given as 16° 54′ E., in 1914, decreasing 9′ annually.

(*a*) Variation in 1920 will be $16° 54' - 54'$ $(9' \times 6') = 16° 0''$.

(*b*) Magnetic Bearing of A from B will be $120° - 16° 0'$ (Variation is subtracted as it is East) $=104° 0'$.

Deviation.—In addition to the Earth's magnetism, the compass needle is subjected to the influence of the permanent and induced magnetism of the Aircraft. The effect of this is that the compass needle does not

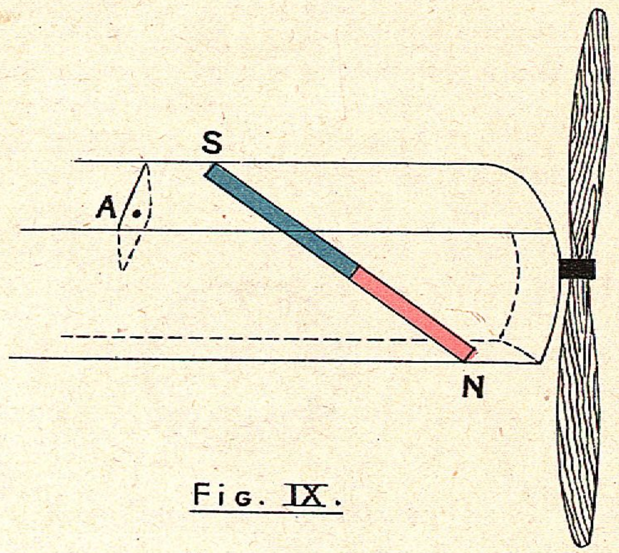

Fig. IX.

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always lie in the magnetic meridian, but generally to one or other side of it, and this gives what is called Deviation.

This is the second important correction that affects the magnetic compass, and it may be briefly stated as follows :—

Deviation is the angle between the compass North (which is the direction in which the compass needle is pointing) and the magnetic meridian.

Causes of Deviation.—If an Aircraft were built entirely of non-magnetic material the compass should have no deviation, but since steel and hard iron are incorporated in its structure, a permanent magnetic system is set up having two distinct poles.

There is also a further source of error from the soft iron which is usually found in an Aircraft and which may be quite suddenly magnetised and demagnetised.

Permanent Magnetism.—In the process of constructing an Aircraft the iron and steel parts usually acquire an excess of permanent magnetism, which, however, soon gets shaken out, leaving a certain definite amount of permanent magnetism.

The Aircraft will then act as a permanent magnet with its poles lying in some definite direction.

When, therefore, the compass is fitted in the machine, it amounts to placing it in the vicinity of the poles of a permanent magnet, which will turn round with the Aircraft.

For example, take an Aircraft having a red pole low down, forward on the starboard side, and a blue pole high up, further aft on the port side.

The compass being in the midships line and abaft both of these poles, its permanent magnetism would be represented as in Fig. IX.

It will be apparent, therefore, that the deviation will be different on each of the cardinal and quadrantal points of the compass, and that in order to correct and find out what these errors are, the Aircraft in which the compass is fitted must be turned round to each of these points, and the readings of the compass taken and compared with a standard compass, unaffected by any local influences.

It is not proposed to go into the theory of Deviation and all the causes and influences of the magnetic iron and steel in an Aircraft, beyond explaining how these influences are counteracted and corrected.

Practical Swinging for Compass Adjustment.—The process of adjusting the compass and subsequently determining the errors remaining in a machine is known as swinging.

For this purpose it is usual to lay out on the aerodrome a swinging base. This consists of eight lines across the surface of the ground, radiating from some central point, which are respectively magnetic north, north-east, east, south-east, south, south-west, west, north-west.

It is thus possible to head the Aircraft by means of those lines over any of the eight points, and the error in the reading of the compass is the deviation of that head.

The swinging base should be laid out carefully on the aerodrome, the following points being borne in mind.:—

(i) It must be level.

(ii) It must be entirely free from any local magnetic influence, such as sheds, railway lines, electric cables, etc.

(If possible it should be situated at least 75 yds. away from any such objects).

Having selected a suitable site which fulfils as far as possible the above conditions, drive a peg into the ground and over it set up a landing compass.

Now attach a piece of string to this peg, about 20ft. long, and with this describe a circle of 20-ft. radius.

Bearings are now made by means of the landing compass on north, north-east, east, etc., and a peg driven in on the circumference of the circle to correspond to each of these bearings, which are, it should be noted, the cardinal and quadrantal points. These pegs should now be joined up by string or tape, or painted on the ground—north to south, east to west, etc., so that they form a base upon which to swing the machine.

It is possible that the lines joining the pegs do not meet accurately at the centre point. If this is so it means that one or more of the points has been incorrectly laid off and the base must be again checked.

This is done either by taking the landing compass used in setting out the base some distance away and taking back bearings on two pegs in transit, or else by taking another landing compass, placing it some distance away from the base and taking reciprocal bearings of the one in the centre of the base.

In both cases care must be taken to see that the landing compass which is used for taking the reciprocal or back bearings is itself entirely free from any local attraction.

The method just described is used for laying out a temporary swinging base, but most aerodromes have a permanent base in the form of a circle of concrete of 20-ft. radius with the eight cardinal points and quadrantal points marked on the outer circumference.

How to Swing an Aircraft for Compass Adjustment.—First of all the Aircraft must be put in normal flying trim. That is to say, all additional gear, such as bombs, guns, very pistols, etc., must be in their accustomed places.

If the Aircraft is an aeroplane or a seaplane whose beach trolley has pneumatic tyres, they should be equally inflated, so that it may rest level on t e ground.

Now wheel the Aircraft on to the swinging base and place it over the centre, with the head pointing north.

The Aircraft should now be placed in its normal level flying position, by supporting the tail on a trestle. Two plumb lines are now fixed, one on to the propeller boss and one on the stern, so that the bobs hang just clear of the ground, care being taken to see that they are both in the centre fore-and-aft line of the machine.

With the help of these plumb lines the Aircraft can now be accurately aligned on any of the magnetic points indicated by the cord and pegs.

Precautions to be Taken before Actually Swinging.—The Aircraft is now in the correct position to begin swinging, but there are four points in connection with the compass itself that must be first examined.

(i) To see that it is perfectly upright when the machine is in flying position.

(ii) To see that the lubber line or lubber's point is exactly parallel to the fore-and-aft line of the compass.

(iii) To see that the magnet holder is empty and in its correct position, mmediately above or below the pivot of the compass, with its slots pointing in a fore-and-aft or athwartships direction.

(iv) To see that the card and needles are not "sticky." This may be done by deflecting the needle 20° to 30° and observing if it comes to rest in exactly the same point again.

Swinging.—The compass will first be adjusted with the machine heading on one of the cardinal points, usually magnetic North.

Any deviation found must be corrected and eliminated as far as possible by means of compensating magnets placed in the athwartships receptacles of the magnet holder, *i.e.*, at right angles to the magnetic meridian.

The operation is then repeated on the east point, but in this case the magnets, being always placed at right angles to the magnetic meridian, will be inserted in the fore-and-aft slots instead of athwartships.

If the compass has been accurately fitted in the machine the adjustments that have been made on north and east should give correct readings on the reciprocal headings, south and west.

In practice, however, this is rarely found to be the case and the adjustment is as follows: The error occuring on the reciprocal heading will not be entirely eliminated but will be halved, that is to say, the compass should always be adjusted so as to show an equally small deviation on each of the opposite cardinal points, *i.e.*, north and south or east and west.

The following typical example will help to explain this:

After correction the reading on east point was 91°.

On the machine being headed west the compass is found to read 263°.

The final adjustment must be made, therefore, so that the readings are approximately 87° on east point and 267° on west point.

This will of course necessitate a rearrangement of the compensating magnets on the fore-and-aft slots, which rearrangement will naturally affect the readings on the points previously checked.

Fresh readings must, therefore, be taken on these headings.

The deviation of the cardinal points having been measured, the next step is to take readings on the four quadrantal points. No attempt, however, must be made to correct any error found on these headings.

Although the compensating magnets can only be used on the cardinal points to correct the permanent or sub-permanent magnetism in the machine, it is always necessary to take the compass readings on the quadrantal points as well in order to ascertain the "soft-iron" and residual errors occurring on these headings.

Correcting Magnets.—The small bar magnets employed for correcting deviation are usually called "compensating magnets." Several sizes are in use.

For R.A.F. Mark II, Pattern 253, etc., the usual size is $2'' \times 3/32''$, for smaller type 5/17″ compasses there are three sizes, $1\frac{1}{2}'' \times 1/32''$, $1\frac{1}{2}'' \times 1/16''$ and $1\frac{1}{2}'' \times 3/32''$.

Compensating magnets are often too strong or the slots in the magnet holder may be too close together, to obtain the required fine adjustment.

Consequently, in order to get accurate and well balanced readings it is frequently necessary to resort to various expedients.

The strength of a magnet may always be reduced by snipping small pieces off the end, or, again, a weak magnetic effect may be obtained by opposing the poles of two magnets placed in the same or different slots.

If the first method is resorted to, it should be noted that the magnet must never be reduced to less than half the length of the slot in which it is placed.

Soft Iron Errors.—It has been explained in Section I of this Chapter that soft iron, although having no power of retaining magnetism, is liable to become instantly magnetised if exposed to a magnetic force.

Since in an Aircraft there is necessarily a certain amount of soft iron which is continually under the influence of the Earth's magnetism, its effect on the compass is of considerable importance, producing what are known as quadrantal errors.

It is often assumed that because the compass readings are correct on, say, north and east, there will be no deviation on north-east; this is, however, not the case, because typical "soft iron" error is never indicated when the machine is headed on any of the cardinal points.

"Soft iron" trouble may be detected on most machines, and is sometimes of a serious nature, in that it may possibly amount to as much as 10° or 12° if the compass has been badly placed.

Quadrantal error is confusing at first, as deviation of this kind is always alternately easterly and westerly on the successive quadrantal points.

It is generally produced by a mass of "soft iron" in the form of a horizontal bar lying across the machine. The "induced" magnetism in such a mass will always cause easterly deviation when the machine is headed on a north-east bearing, westerly deviation on south-east, and so on. Although it causes no deviation on any of the cardinal points, it will weaken the directive force, and therefore make the compass more sluggish on east and west.

In ships, quadrantal error is eliminated by means of "soft iron" spheres, and in some of the earlier aeroplane compasses "soft iron" correcting rings were used for the same purpose, but these are not issued with any of the later types.

Although it may not be possible to correct the deviation due to this cause, readings should always be taken on the quadrantal points in order to tabulate the error for the information of the pilot. By interpolation he will then be able to steer a compass course within a degree or two on any point, which is not possible if the error on the cardinal points only is known.

Faulty Alignment of Lubber Line.—If the lubber line is not correctly placed in the longitudinal axis of the machine, accurate readings can never be obtained, for if a correction be made on one point the error (when due to this cause) will be doubled on the opposite bearing.

It may be assumed (and especially if the compass has been centrally fitted) that if the lubber line is at an angle with the fore-and-aft line of the aeroplane the total easterly deviation will exceed the total westerly deviation or *vice versa*.

The following is an example:—

Compass reads—

358° on N., *i.e.*, an apparent easterly deviation of 2°.
42° on N.E., *i.e.*, an apparent easterly deviation of 3°.
87° on E., *i.e.*, an apparent easterly deviation of 3°.
135° on S.E., deviation nil.
178° on S., *i.e.*, an apparent easterly deviation of 2°.
221° on S.W., *i.e.*, an apparent easterly deviation of 4°.
267° on W., *i.e.*, an apparent easterly deviation of 3°.
316° on N.W., *i.e.*, an apparently westerly deviation of 1°.

Total easterly error = 17° − 1 = 16°

In this case the mean of the apparent deviation on the eight bearings shows that the lubber line is 2° out of true in an anti-clockwise direction. In order to align it correctly it should, therefore, be moved 2° to starboard.

In this connection the following points should be noted :—

A constant error in one direction may be produced by—

(i) Induction in horizontal soft iron unsymmetrically distributed round the compass.

(ii) Lubber line improperly aligned.

(iii) The needles of the compass not being parallel to the north and south line of the compass card.

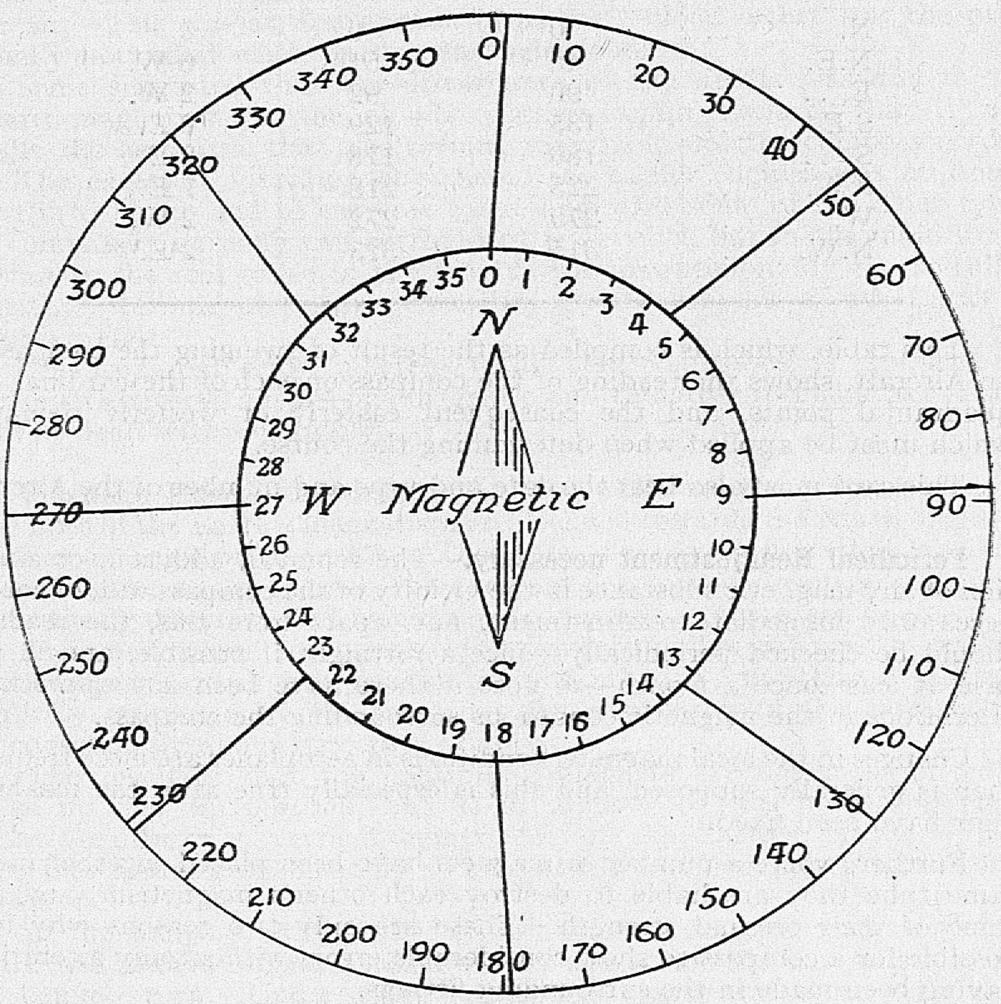

FIG. X.—MACKENZIE AERO DEVIATION CARD.

It is just possible that two, or even three, of these causes may be present at the same time. This being so the above formula must be regarded as a guide for correcting a very common fault, rather than an infallible rule.

Faulty alignment of the lubber line owing to ignorant or more often careless fitting of the compass is a very frequent cause of trouble, and is one that should be carefully guarded against.

Deviation Card.—A special card is provided on which the deviations are recorded, and which is attached to the instrument board in full view of the pilot, and as close to the compass as possible.

A typical deviation card is illustrated below :—

Aeroplane *Type Re.* 8.

No. A. 2619.

Date 30/8/18.

	Magnetic.	*Compass Reads.*	*Deviation.*
N. ..	0	0	0
N.E. ..	45	51	6 W.
E.	90	92	2 W.
S.E. ..	135	129	6 E.
S.	180	178	2 E.
S.W. ..	225	218	7 E.
W. ..	270	272	2 W.
N.W. ..	315	313	2 E.

This table, which is compiled as the result of swinging the compass in an Aircraft, shows the reading of the compass on each of the cardinal and quadrantal points, and the consequent easterly or westerly deviation which must be applied when determining the course.

This card must also bear the date and type and number of the Aircraft.

Periodical Readjustment necessary.—The removal, addition, or alteration of any magnetic substance in the vicinity of the compass will, of course, necessitate immediate readjustment, but, apart from this, the readings should be checked periodically—once a fortnight if possible, and in any case at least once a month—to note if there have been any appreciable alterations in the magnetic conditions surrounding the compass.

Changes in the local magnetic conditions in aeroplanes are more frequent than is generally supposed, and this is especially true after the machine-guns have been fixed.

Further, where a number of magnets have been placed together in the same tube they are liable to destroy each other's magnetism, and lose some of their original strength. These are only two reasons why it is possible for a compass to show considerable errors without any alterations having been made in the surrounding fittings.

Some Points on Adjusting Compasses.—The following points must always be remembered when adjusting a compass :—

1. When correcting deviation the compensating magnets must always be placed at right angles to the magnetic meridian. That is to say, when the machine is headed north or south the athwartships slots are to be used, when the machine is headed east or west the fore-and-aft slots are to be used.

2. No attempt must be made to correct deviation on any of the quadrantal points. It is impossible to eliminate this with ordinary compensating magnets.

3. The error on the cardinal points must always be balanced, that is to say, the compass must be adjusted so that the deviation is equally small on each of the opposite readings—north and south, or east and west.

4. Any rearrangement of the magnets will necessitate fresh readings being taken on all the previously tested headings.

5. After adjustment the magnet holder must be carefully secured. This point is often overlooked.

FLYING ERRORS.

Northerly Turning Error.—In the early days of flying it was remarked that a compass frequently behaved in an unexpected manner when in the air. This was at first spoken of as the "cloud error," for the pilot usually noticed it when passing through clouds.

Some suggested that the disturbance of the needle was due to the electro-magnetism in the clouds. Others, again, declared that it was really the aeroplane that was turning round and not the compass needle.

The excessive vibration of some of the earlier engines was no doubt partly to blame and in extreme cases, and with some of the older types of compasses, actually caused the card to revolve, but in the majority of instances the real cause of the trouble was unquestionably the so-called northerly turning error, first described by the late Dr. Keith Lucas at Farnborough.

This apparent error, inherent to all aero compasses, is produced by two contributory causes—one magnetic and the other mechanical. These will be dealt with separately.

Magnetic Effect.—In this part of the world at the present moment the lines of the Earth's magnetism are declined towards the North Magnetic Pole at an angle of about 67°. Therefore, if perfectly free (that is to say, free to move in any plane), the compass needle would not only point in a northerly direction, but would dip downwards at this steep angle.

In some types of compasses this downward pull is balanced by making the compass card slightly heavier on its south side; in others it is almost entirely overcome by the fact that the suspension of the card system is considerably above its centre of gravity.

The result is that the controlling magnets are never permitted to take up this dip position, but lie in a more or less horizontal plane. Consequently, the vertical component of the Earth's magnetic force becomes ineffective—but only so long as the card remains in a horizontal position.

If the compass be tilted 20° or 30°, under ordinary circumstances the card will always remain horizontal, but this is not the case when making a banked turn. Under these conditions centrifugal force will cause everything in the machine to "bank" at the same time—including the compass card, which consequently retains its relative position at right angles to the pivot.

Now, consider an aeroplane with a sensitive compass making a turn from north to east. It will be convenient to consider this turn in three phases.

The first phase will include a bank with the right wing downwards. In consequence of this the axis about which the compass card turns becomes tilted in an approximate east and west plane with its lower extremity towards the west.

In this position the effect of the vertical component of the Earth's force will be changed, and, instead of tending to throw the card out of

balance, it will cause it to rotate by dragging the north-seeking end of the needle downwards—that is to say, towards the centre of the machine's turn. The angular velocity of the needle produced by this downward drag may be less than, equal to, or greater than the turning movement of the machine. If the latter is the case it is obvious that a westerly instead of an easterly turn will be registered against the lubber line representing the head of the machine.

In the second phase it will be assumed that the machine has nearly completed its turn and is still banking with its right wing down.

The axis of the card is now tilted in an approximate north and south plane, its lower extremity towards the north. Should the angle of the bank be the exact complement of the Earth's dip, viz., 23° (90° − 67° = 23°), the lines of the Earth's force will be passing through the pivot of the compass and the needle will be without magnetic control. But if the angle of the bank is greater than 23°, the north seeking end of the needle will tend to point downwards, which (in this position) means that it will tend to point towards the "south." Consequently, the same rotary movement will be continued.

In the assumed third phase, the machine is imagined to have flattened out on an easterly course. The compass is controlled once more, only by the horizontal component of the Earth's force.

If the needle's momentum has carried it past the north and south meridian it will naturally continue in the same direction, since this will be the nearest way for it to return to its normal position.

In the extreme case just described the compass has shown an apparent westerly or anti-clockwise turn of 270°, whereas the machine has actually turned through 90° in a clockwise direction.

In the majority of cases the error is not so exaggerated, but it very often happens that the needle moves so quickly, or very nearly as quickly, as the machine, that is to say, the needle appears to follow the machine's nose round, so that little or no turn is registered against the lubber line.

Mechanical Effect.—As has been pointed out above, in most types of compasses the south side of the needle is weighted to counteract the downward pull of the Earth's force. But this weight is only balanced by the compensating magnetic couple in a vertical plane, and thus, when the machine turns, centrifugal force will tend to throw this weighted end outwards. Consequently, when turning off a northerly course the north seeking end will be forced round in the direction of the machine's turn just as it was by the magnetic forces described above. When turning off a southerly course, on the other hand, the tendency will be for the card to rotate in an opposite sense to the machine.

In conclusion, the effects of the northerly turning error may be briefly summarized as follows :—

(i) The compass greatly minimizes a banked turn from a northerly course, and, in extreme cases, will indicate a turn in the opposite direction.

(ii) A turn from a southerly course is always exaggerated, but the degree of error is not so great.

It should be noted that the northerly turning error exists only during the period over which the turn lasts. As soon as the turn is completed, the compass will again assume its correct position and indicate the course of the machine.

Speed Error.—Speed error is produced by the inertia of the heavier south seeking end on a sudden increase or decrease of speed during a straight east or west course. A rapid acceleration will naturally cause the heavier south seeking end to lag at first, and this will sometimes induce

the card to swing off as much as 20° or 25°. Of course the opposite obtains on a sudden decceleration, and in this case the south end will swing forward instead of back.

Speed error is seldom noticeable in smooth air but may be troublesome in bumpy weather and especially in clouds.

Liquid Disturbance Error.—A series of quick evolutions are likely to disturb the compass liquid, which may cause the card to be carried round in the direction of the swirl. But in a compass with a strong magnetic control, if the bowl has been completely filled, the " carry off " is not serious, and the card will settle again in a few seconds.

Conclusion.—Practical use of the compass.

To steer a compass course in any direction requires practice, not only to keep the head of the machine steady (which is often difficult in " bumpy " weather), but also to gauge the necessary allowance to be made for drift.

The various errors to which the magnetic compass is subject appear at first sight very formidable. They are, however, really very simple, and their correction once understood will present few difficulties.

CHAPTER IV.

THE EFFECT OF WIND ON AN AIRCRAFT, INCLUDING SIMPLE DRIFT PROBLEMS.

Introduction.—The atmosphere may well be compared to the sea, a very unstable element, subject to continual motion and change. The currents of the sea can be measured and charted, but those of the air are not yet bound by any known rule or formula. Aircraft, while flying, are necessarily under the influence of the atmosphere, and consequently the problem of conducting a machine between two places situated some distance apart is complicated by the movements of the atmosphere; for the air is seldom so still that the course steered follows the track over the ground.

The science of air pilotage aims at the correction of the atmospheric influence by making the necessary allowances to enable the Aircraft to make good the track between any two places, whatever may be the movements of the upper air.

Drift.—An Aircraft on leaving the ground becomes part of the moving atmosphere, just as a boat on a tidal river, and will behave in much the same manner.

(1) A boat travelling up stream will make less way than when travelling down stream, just as an Aircraft flying against and with the wind.

(2) Similarly, a boat crossing a stream with a strong current running will have to steer at some point above or below the proposed arrival point, in order to allow for the effect of the current. An Aircraft flying in a wind which is blowing at an angle to its track must carry out exactly the same procedure.

The problem presented by (1) above is simple, provided the strength of the wind is more or less accurately known, as the effect will be either to retard or accelerate the speed of the Aircraft on its course, without interfering with the track made good.

The problem of an Aircraft flying from one place to another when the wind is blowing at an angle to its course is more difficult and introduces the question of drift.

Drift is the difference between the direction made good and the direction steered, or the angular difference between the track of an Aircraft and its fore-and-aft line. It results, as has already been stated, from the action of the wind and is similar to the leeway made by a sailing vessel or by a boat crossing a river.

Parallelogram of Velocities.—The method employed to calculate the effect of the wind on an Aircraft flying from one place to another is known as the parallelogram of velocities, by means of which the wind, the track, and the course steered are represented graphically.

The parallelogram of velocities depends on the following facts :—

Any force can be represented in magnitude and direction by a straight line, and any force acting on a body to produce motion can be split up into two or more components.

Conversely, any two forces acting together on a body can be compounded into one resultant force.

In Fig. XI, let A be any body, on which two forces B and C are acting. A will not move in the direction AB nor in the direction AC, but in the resultant direction AD.

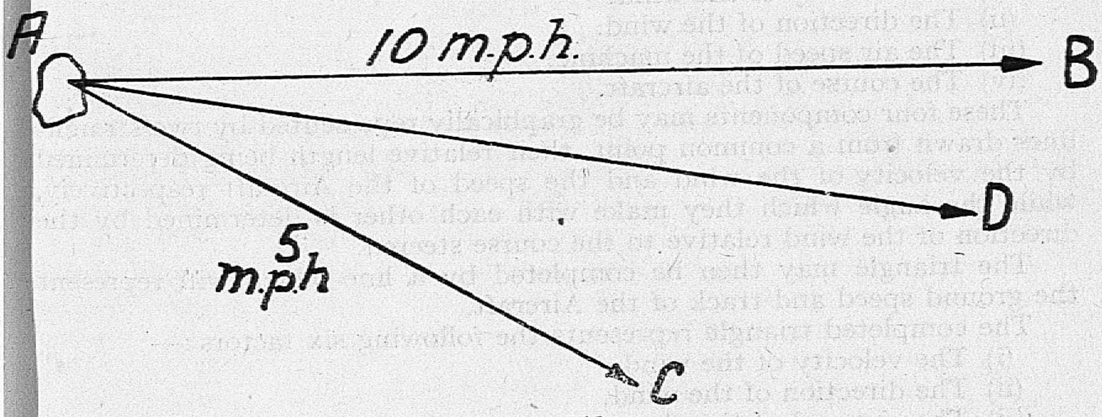

FIG. XI.

The value of this resultant is obtained by the parallelogram of velocities, Fig. XII.

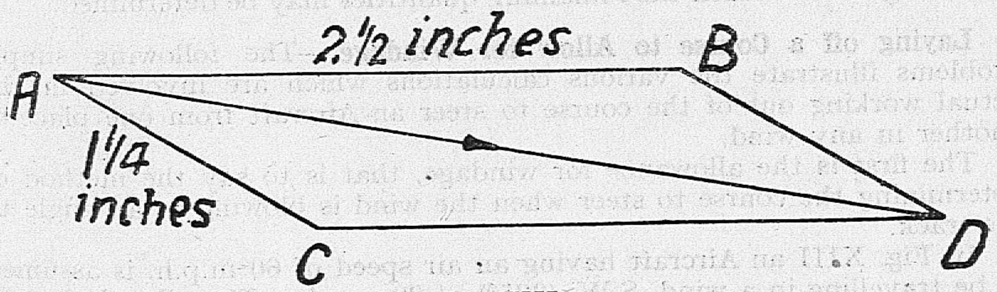

FIG. XII.

From any point A, lay off AB, to represent in velocity and direction the force B acting on the body A. From A, lay off AC, to represent the force C in velocity and direction. Complete the parallelogram ABCD.

Then AD represents, in direction and length, the velocity and direction of the resultant motion of A.

Thus, if the force B produced a motion of 10 miles per hour in a direction AB, the body A would move 10 miles along AB in one hour, if acted upon by B alone, and similarly if the force C produced a motion of 5 m.p.h. in the direction AC, A would move five miles along AC in one hour. If, however, both forces are acting together, A cannot move in the direction AB or AC, but will take up the direction AD, with a velocity compounded from the other two.

In Fig. XII let AB be 10 in. and AC 5 in., then AD 13 in. represents the velocity of A on a scale of 1 in. per mile per hour, *i.e.*, 13 m.p.h., and the direction AD represents the direction taken up by A.

In practice it is found convenient to dispense with the sides AB, BD (Fig. XII), and use the "Triangle of Velocities" ACD to solve the problem.

Triangle of Velocities.—This principle is used to determine the resultant of the various components which define the track and the ground speed of an aircraft in flight.

These components are four :—

(i) The velocity of the wind.
(ii) The direction of the wind.
(iii) The air speed of the machine.
(iv) The course of the aircraft.

These four components may be graphically represented by two straight lines drawn from a common point, their relative length being determined by the velocity of the wind and the speed of the Aircraft respectively, while the angle which they make with each other is determined by the direction of the wind relative to the course steered.

The triangle may then be completed by a line which will represent the ground speed and track of the Aircraft.

The completed triangle represents the following six factors :—

(i) The velocity of the wind.
(ii) The direction of the wind.
(iii) The airspeed of the aircraft.
(iv) The ground speed of the aircraft.
(v) The course steered.
(vi) The track or course made good.

A knowledge of any four of these quantities is sufficient to complete the triangle from which the remaining quantities may be determined.

Laying off a Course to Allow for Windage.—The following simple problems illustrate the various calculations which are involved in the actual working out of the course to steer an Aircraft from one place to another in any wind.

The first is the allowance for windage, that is to say the method of determining the course to steer when the wind is blowing at an angle to the track.

In Fig. XIII an Aircraft having an air speed of 60 m.p.h. is assumed to be travelling in a wind, S.W. (225°) of 20 m.p.h. The pilot desires to make good a track due south (180°).

From any point P, lay off PW, to represent the direction and distance that the wind would blow the Aircraft in one hour, *i.e.*, towards the N.E. (45°), 20 miles. The scale being 1 in. to 20 miles, lay off PW 45°—1 in. PN being true north.

Lay off PS the track due south (180°) with centre W, and radius 3 in. (representing 60 miles to scale, the distance the craft would travel in still air in one hour) describe an arc cutting PS in T. Join WT, and from P lay off PT′ parallel to WT.

Angle NPT′ (measured clockwise from N) is the course to steer, and PT to scale the distance travelled in one hour, *i.e.*, the ground speed.

The head of the craft will therefore be NPT, and it will be travelling along PT, making good a track S. (180°). TPT′ will therefore be the angle of drift.

To Calculate the Speed and Direction of the Wind by Plotting.—In Fig. XIV let it be assumed that an Aircraft starts from A in still air and flies in the direction AC for one hour, at an air speed of 60 m.p.h.

At the end of one hour it will have reached C, distant 60 miles from A. Now, suppose that it starts from A steering in the direction AC, but at the end of one hour it is at T, distant 70 miles from A, in a direction AT. It has, therefore, made good the track AT at a ground speed of 70 m.p.h., while steering AC at an air speed of 60 m.p.h.

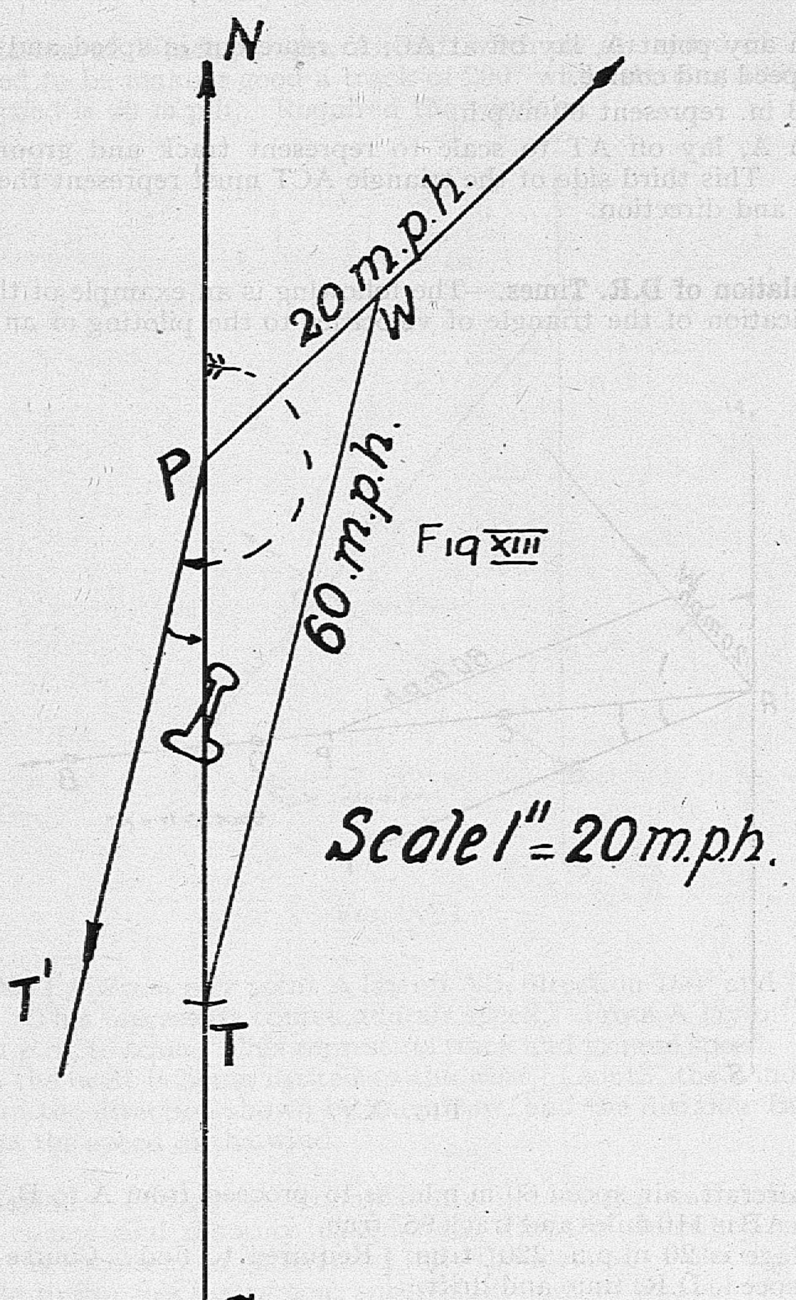

FIG. XIII.

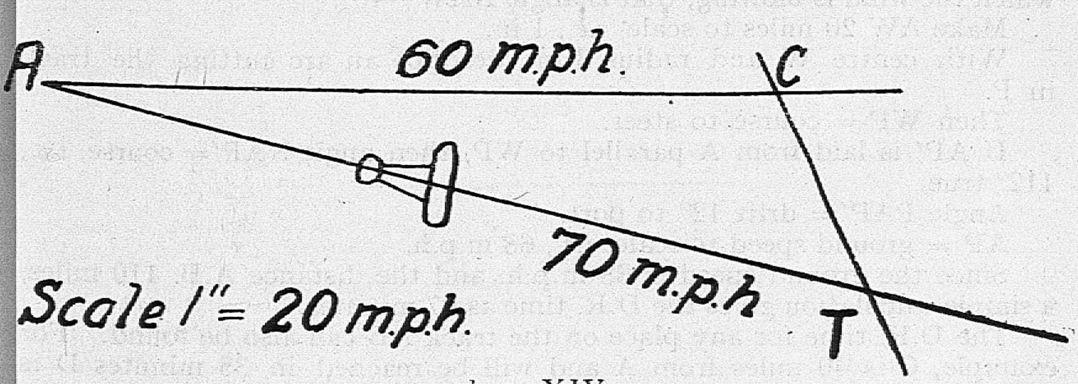

FIG. XIV.

From any point A, lay off at AC, to represent in speed and direction the air speed and course.

Let 3 in. represent 60 m.p.h.

From A, lay off AT to scale to represent track and ground speed. Join CT. This third side of the triangle ACT must represent the windage in speed and direction.

Calculation of D.R. Times.—The following is an example of the practical application of the triangle of velocities to the piloting of an Aircraft.

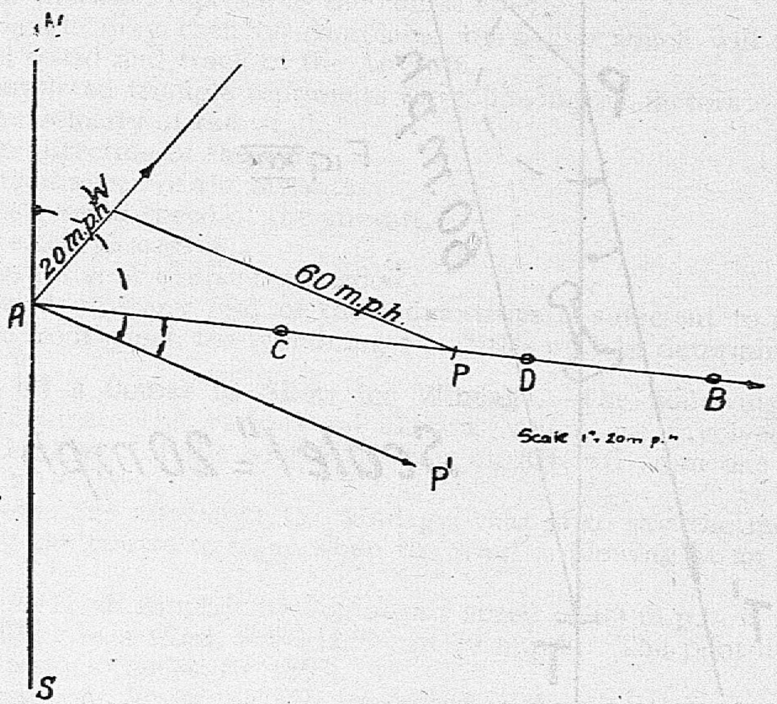

FIG. XV.

An Aircraft, air speed 60 m.p.h., is to proceed from A to B, Fig. XV. Distance AB is 110 miles and track 95° true.

Windage is 20 m.p.h. 220° true. Required to find: Course to steer. Ground speed, D.R. time and drift.

Join AB, the track. From A, lay off AW in the direction towards which the wind is blowing, that is angle NAW—40°.

Make AW 20 miles to scale, *i.e.*, 1 in.

With centre W and radius 3 in., describe an arc cutting the track in P.

Then WP = course to steer.

If AP′ is laid from A parallel to WP, then angle NAP′= course, *i.e.*, 112° true.

Angle PAP′= drift 12° to port.

AP = ground speed to scale, *i.e.*, 68 m.p.h.

Since the ground speed is 68 m.p.h. and the distance A.B. 110 miles, a simple calculation gives the D.R. time as 97 minutes.

The D.R. time for any place on the track AB can also be found. For example, C is 40 miles from A and will be reached in 35 minutes D is 80 miles from A and will be reached in 70½ minutes.

Calculation of Windage.—An Aircraft with an air speed of 75 m.p.h. is observed to be making good a track of 200° while steering 180°, and its ground speed is 60 m.p.h. Required the windage.

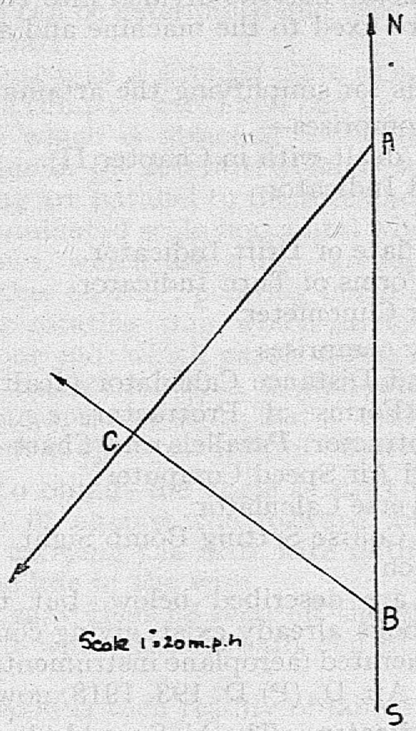

Fig. XVI.

Fig. XVI. From any point A lay off AB, direction 180° and 75 m.p.h., to scale. This represents course and air speed. From A lay off AC, 220° and 60 m.p.h., to scale. This represents track and ground speed. Join BC.

Since the craft is being drifted to the west of south, the wind must be blowing in the direction shown by the arrow, and the distance BC to scale represents the speed of the wind.

Conclusion.—The above examples are in practice calculated on the Aircraft course and distance calculation, which is described in Chapter VI, but it is necessary to understand fully the method of plotting, in order to be able to use this instrument successfully and to be able to work with pencil and protractor only, if the occasion arises.

CHAPTER V.

INSTRUMENTS.

Air pilotage instruments may be divided into two classes :—

(*a*) Those which are fixed to the machine and are, generally speaking, indispensable.

(*b*) Extraneous aids for simplifying the attainment of results.

The first category comprises—

(i) The Compass (dealt with in Chapter II).
(ii) The Air Speed Indicator.
(iii) The Altimeter.
(iv) The Bearing Plate or Drift Indicator.
(v) The Various Forms of Turn Indicator.
(vi) The Bubble or Clinometer.

The second category comprises—

(i) The Course and Distance Calculator (dealt with in Chapter VI).
(ii) The Various Forms of Protractor, *e.g.*, Douglas Protractor, Bigsworth Protractor, Parallels and Chart Board.
(iii) The Appleyard Air Speed Computer.
(iv) The Card Traverse Calculator.
(v) The Wimperis Course Setting Bomb Sight.
(vi) The Stop Watch.

These instruments are described below, but they are only briefly discussed, since hand-books already exist, giving complete details of most of the instruments enumerated (aeroplane instruments, issued by Controller, Technical Department, Ap. D. (P) D. 193, 1918, now underrevision).

(ii) The Air Speed Indicator.—The Air Speed Indicator gives the air speed of the Aircraft. It is worked by air pressure and its accuracy is therefore affected by variations in height and by changes of the barometric pressure.

As the altitude increases the density of the air decreases, and consequently the Air Speed Indicator registers less than the True Air Speed.

A ready means of correcting for this is provided by the Appleyard Air Speed Computer. As a rough rule, however, the pilot may add $1\frac{1}{2}$ per cent. to the indicated air speed for every 1,000 ft. of rise.

(iii) The Altimeter.—This instrument is in effect an Aneroid Barometer, but instead of being graduated to show changes of pressure it is graduated to show changes of height.

Altimeters are made to read to various heights according to the type of machine to which they are fitted.

This instrument is affected by changes of barometric pressure, independently of height. It is, however, possible to correct for this by turning the graduated disc till the needle points to zero, which should always be done just before starting on a flight.

When carrying out a long flight, changes of weather, and hence of barometric pressure, may affect the accuracy of the instrument, but inaccuracies due to such change will usually be insignificant during a flight of only a few hours duration.

It must always be borne in mind that the height recorded is that above the point of departure, and not necessarily that above the point of arrival, and the map should therefore be studied first and the heights above sea-level of the points of departure and arrival compared.

By carefully attending to these details before commencing a cross-country flight, every reliance may be placed on the altimeter as being a fairly accurate guide to the height of the Aircraft.

(iv) **The Bearing Plate or Drift Indicator.**—This instrument has been developed for aerial use from the Nautical Bearing Plate or Pelorus, and it is used to make observations of fixed objects on the Earth's surface over which the Aircraft is travelling. By adjusting the bearing plate until the object or objects pass straight along the sights, the amount of drift the Aircraft is making can be determined and used to check the track being made good by the Aircraft.

The instrument consists of a circular plate or scale, which is graduated from 0° to 360° (as the compass card) and can be rotated about its centre, inside a fixed ring to which is attached a standard. The standard fits into a socket on the side of the Aircraft, which is so arranged that the two arrows on the fixed ring are parallel to the fore-and-aft line of the machine and the plane of the graduated scale horizontal when the machine is flying level. (The two arrows, which are white, are opposite each other, one being on 0° and the other on 180°, pointing north and south respectively).

Outside is another rotating ring, which carries a height scale and a drift wire, hinged at one end, which passes across the centre of the three concentric rings. On the scale, which is graduated in thousands of feet up to 2,500′, is a sliding aperture sight, and at each end a fore-sight. The centre of the instrument is open to admit of observations on the ground.

Method of Use.—To obtain the angle of drift of the machine, set the graduated circle with 0° against the forward arrow on the ring, then rotate the outer ring carrying the drift wire until objects on the ground pass directly along the line of the wire.

The angle of drift may then be read off the graduated scale opposite the arrow at the point where the forward end of the drift wire cuts the scale.

The course made good is then readily obtained by adding the angle of drift to the compass reading.

It has been stated that the vertical arm is graduated in thousands of feet up to 2,500′. If the Aircraft is flying at 2,500′ and the ring is set to that height, the time in seconds taken for any object to pass from the foremost sight till vertically below, is the time in seconds for ½ mile, *i.e.*, ground speed for ½ mile.

If the Aircraft is flying at 5,000′ the ring must be set at 2,500′ and then the distance represented is one mile, and so on, in proportion to the height.

The bearing plate or drift indicator can be fitted for the use of either the pilot or the observer, but is more conveniently used by the latter. It should, however, be used continually while piloting to check the drift of the craft, thus providing a check on the dead reckoning position, and also indicating any change of wind.

The following examples will help to make the use of this instrument clear:—

(1) A pilot starts out on a flight having first of all worked out the course to steer to make good the required track. He reckons that he must steer 40° to make good a track of 65°, showing that the drift is 25° to starboard.

After starting he proceeds to check the drift and finds that it is 15° instead of 25° to starboard. This means that the Aircraft is now heading 40°, but only making good a track of 55°, instead of 65°.

He accordingly alters course to 50°, *i.e.*, 10° to starboard, when the drift will be approximately 15° and the track 65°.

(2) To find the course quickly when only an approximate direction of the wind is known.

The pilot knows that the rough direction of the wind is N.E. (45° and he wishes to make good a track of 90°.

The pilot must first of all head his machine approximately into the wind and he accordingly steers 70°, and at the same time sets the plate to 70° and the drift bars to 90°. If this approximation is correct, objects on the ground will pass down the bars. If, however, this is not the case, but the bar has to be turned to say 85°, the plate must be turned until 90° is opposite the drift bar, when the course to steer can be read off the lubber line. As soon as the necessary alteration of course has been made, a second check should be taken, when a more accurate result will be obtained.

The ground speed must then be taken and checked to get the dead reckoning.

A point which is worth remembering is, that when the Aircraft is drifting an object which is dead ahead will not pass under the machine. When using the instrument to obtain a bearing, the plate must be set to the magnetic course and a sight taken on to the object by means of the drift bars and the vertical arm.

The reading of the plate nearest the observed object is its magnetic bearing, and the reading furthest from it is the back bearing.

Bearings must always be taken as quickly as possible and the time of the observation carefully noted, otherwise the position or fix thus obtained will be inaccurate, due to the rapid travel of the machine, which is constantly altering the direction of the bearings in relation to each other.

Care must be taken to reset the bearing plate on any alteration of course.

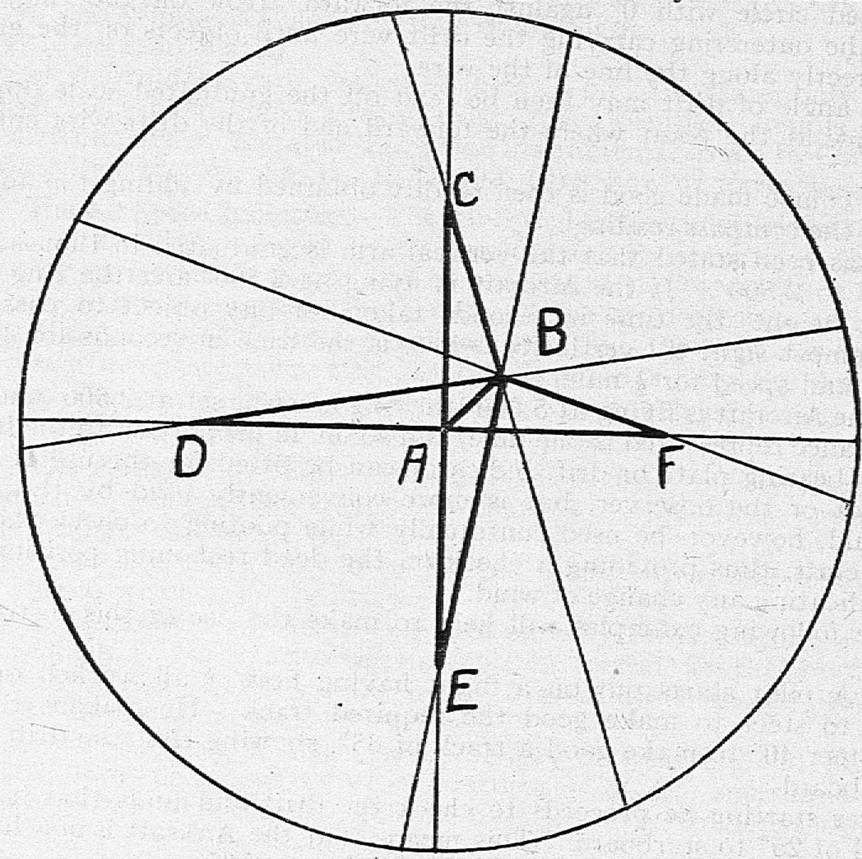

FIG. XVII.

Tail Bearing Plate.—This instrument is designed to enable the drift of an Aircraft to be obtained from any object by flying over it from different directions and noting the drift in each case. When flying over the sea the drift should be obtained in this manner from buoys, lightships, or calcium flares dropped from the machine. A line parallel to

the apparent track of the flare is drawn on the ground glass screen, through the point on the fore-and-aft line of the bearing plate, which is at a distance from the centre proportional to the air speed of the machine.

In Fig. XVII, AC, AD, AE, AF represent in direction four successive courses steered, which in length are proportional to the air speed of the machine.

BC, BD, BE and BF are lines parallel to the track of the flare, *i.e.*, they represent the track made good by the machine.

It is found that all these lines meet in a point B.

Therefore, by joining BA a series of triangles of velocities ABC, ABD, ABE, ABF is formed.

In these triangles AC, AD, AE, AF represent the air speed of the machine in strength and direction, BC, BD, BE, BF represent in direction the successive tracks of the machine.

BA is the third side of each triangle and is the only line which can be drawn common to all the triangles.

Therefore, this must represent the wind in strength and direction, and BC, BD, BE and BF the ground speed and direction of the machine.

This same instrument is fitted with a height bar and may be used as an ordinary drift indicator, and the ground speed obtained by means of a stop watch.

(v) **Turn Indicators.**—The turn indicator is an instrument which shows when an Aircraft is turning, and also gives a rough idea of the rate of the turn. It is a great aid to pilots flying in thick and bumpy weather, since whenever a compass starts swinging, due to unintentional turning of the Aircraft, the turn indicator at once shows the direction of the turn and enables the pilot to straighten out and maintain his course correctly.

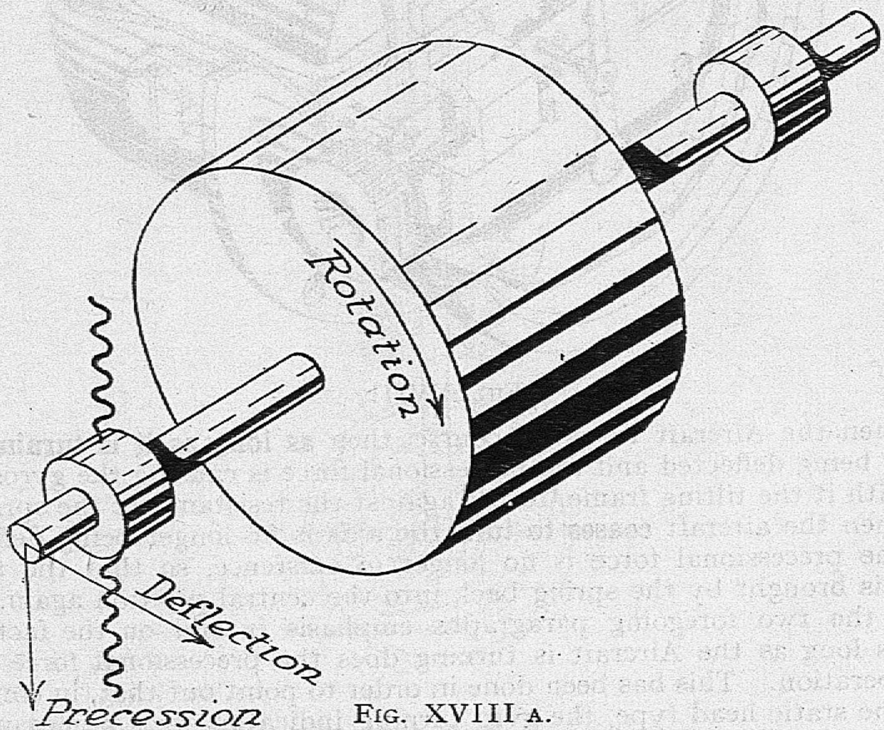

FIG. XVIII A.

There are various forms of this instrument, of which the two principal rely respectively on gyroscopic action and on a difference of pressure at the wing tips of the Aircraft.

Since the gyroscopic form is entirely superseding the static head, the former need only be considered.

The Gyro Turn Indicator.—It is a property of a rotating mass that if the axis of rotation is deflected there is set up a tendency for the axis to move in a plane perpendicular to that in which the deflection has occurred. Thus, if the end of the axis of the disc, which is rotating in a clockwise direction, be deflected to the right, the axis will move downwards, or if deflected to the left will move upwards.

The rotating mass constitutes a gyroscope, and the upward or downward movement of the axis, consequent upon a deflection to the left or right respectively, is known as precession.

If such a gyroscope be mounted in a tilting frame in such a manner that the axis of rotation is parallel with the fore-and-aft axis of the Aircraft, and the frame can tilt about an athwartships horizontal axis under the control of a spring, it will be seen that such a system constitutes a turning indicator.

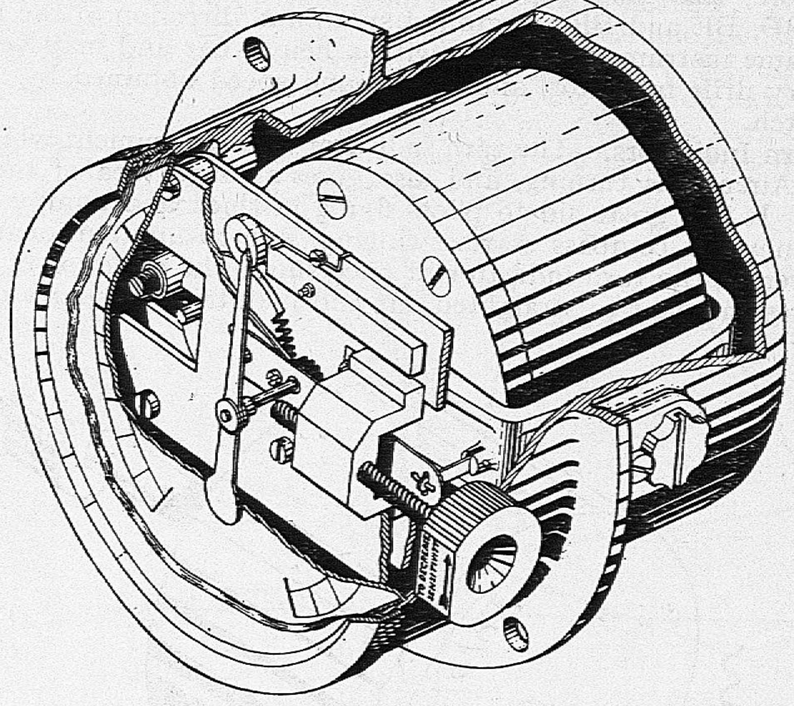

FIG. XVIII.

When the Aircraft turns off course, then **as long as it is turning,** the axis is being deflected and the precessional force is causing the gyroscope, and with it the tilting frame, to tilt against the resistance of the spring.

When the aircraft **ceases to turn** the axis is no longer being deflected and the precessional force is no longer in existence, so that the tilting frame is brought by the spring back into the central position again.

In the two foregoing paragraphs emphasis is laid on the fact that only as long as the Aircraft is turning does the precessional force come into operation. This has been done in order to point out that, in common with the static head type, the gyro turning indicator gives a measure of the rate of turn off course, and only inferentially the extent of the turn.

Two types of gyro turning indicators are under development, the first of which is designed to be mounted in any position on the instrument board. The gyro wheel forms the rotor of a simple three-phase induction motor supplied from slip rings fitted to the generator from which the current for lighting and heating is obtained.

The control takes the form of a leaf spring connected by a link to the tilting frame. A sliding fulcrum provides the means of varying the sensitivity.

A weak auxiliary control, obtained by the reaction of a spring loaded roller against a notched cam, is provided, so that steadiness of the pointer may be ensured in spite of extreme sensitivity. The effect is that a definite though very slow rate of turn must be exceeded before an indication is shown.

Once this rate of turn is exceeded a considerable deflection at once occurs (Figs. XVIII A and XVIII).

In the second (Fig. XIX) type the gyro wheel is drilled with oblique holes, and is disposed in the slip-stream, from the reaction of which it derives its rotation. The tilting frame takes the form of a fork, the handle of which extends inside the cockpit and operates the pointer against variable spring control. A measure of friction damping is provided to ensure steadiness of the pointer.

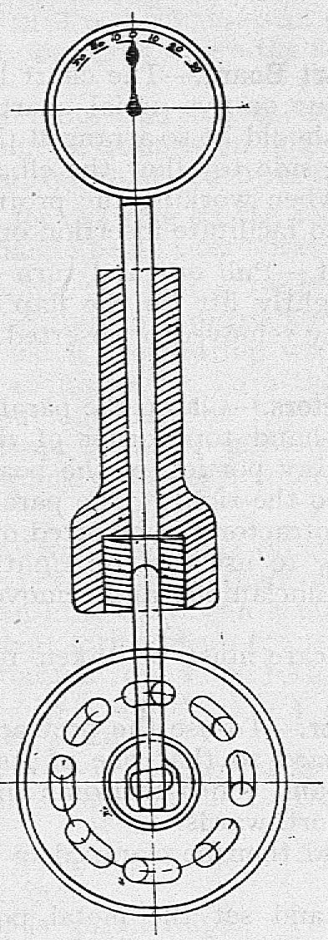

FIG. XIX.—THE R.A.E. TURN INDICATOR.

(ii) **The Bigsworth Protractor and Chart Board.**—This consists of a square chart board covered with celluloid on which lines may be drawn with a special pencil.

A special celluloid protractor attached to a set of movable parallel

arms, which in their turn may be clamped to any edge of the chart board, is provided. The arms are so constructed that the protractor may be moved to any part of the board.

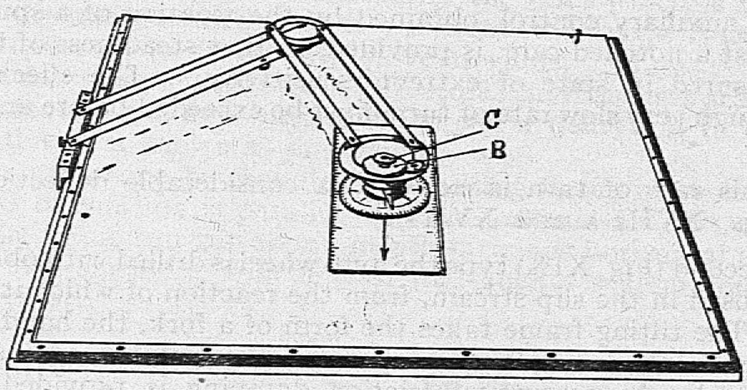

FIG. XX.—BIGSWORTH AERO CHART BOARD WITH COMBINED PARALLELS AND PROTRACTOR.

How to Use the Chart Board.—The chart board is designed to accommodate at one time four or five aerial charts or maps. If it is to be fixed in the Aircraft it should be so arranged that there is a space of about 6 in. on the right-hand side to allow the elbow of the brass parallels to protrude this amount when working the protractor on the extreme right of the board, and also to facilitate insertion or removal of the charts.

To Change the Chart.—Pull out and turn down the brass clip on the right-hand side and slightly lift up the flap of the celluloid cover; the charts can now be easily removed or inserted. The clip must always be replaced afterwards.

Parallels and Protractors.—Clamp the parallels by means of the clamping screw at the right-hand top corner of the board. The protractor can now be used over any portion of the board, provided there is room for the elbow to work to the right. The parallels are fitted with a hinge so that they and the protractor can be lifted off the board if so desired.

When it is necessary to use the top right-hand corner of the board, the parallels should be unclamped and removed to the bottom left-hand corner.

When this is done care must be taken to reset the pointer of the protractor.

To Use the Protractor.—To use the protractor with an ordinary map, first place it on the board so that one of its sides corresponds exactly with one of the north and south meridian lines, care being taken that the arrow is pointing northwards.

The protractor should then be clamped in this position by tightening the central screw B.

Now ease screw C and set the metal pointer so that it indicates magnetic north.

If there is a compass rose on the chart or the angle of variation is shown on the margin of the map, place the side of the protractor coincident with the magnetic meridian and clamp the metal pointer at 0°.

This is the simpler and more direct method. It is now an easy matter to plot any course. All that is necessary is to place the protractor with one of its edges joining the point of departure and the objective.

The metal pointer will then shew the track (magnetic), while the number of miles to be traversed will be indicated by the scale.

By clamping screw B the protractor will act as a parallel rule, and parallel lines may be drawn anywhere over the board.

Knowing the direction and velocity of the wind, the required course may be easily plotted by the usual methods.

To Measure the Distance.—Two protractors are provided which are readily interchangeable by simply unscrewing the screw in the centre on the under side of the protractor by means of the screwdriver provided.

The protractors are graduated—

(*a*) For charts, and

(*b*) For maps.

(*a*) The sides of the protractor are graduated in inches and tenths, and are numbered in the direction of the arrow from the departure point to the objective.

Aerial charts are all drawn on a fixed scale—10 nautical miles to the inch in the case of general charts, and three nautical miles to the inch for coastal charts of Great Britain. Having ascertained the distance in inches and tenths, multiply by the scale of the chart, *i.e.*, distance 4·7″ on a coastal chart, then $4 \cdot 7 \times 3 = 14 \cdot 1$ nautical miles. This protractor is of course equally available for maps where the scale is some fraction or multiple of an inch.

(*b*) The graduation is in miles and halves on a scale of 1/200,000. This scale has been chosen since distances on larger or smaller customary continental scales can be readily calculated from it.

Pencil.—A special pencil for drawing on the celluloid cover is supplied with each board, the marks made being easily erased by the finger.

To Plot a Bearing.—In order to plot a bearing, turn the protractor round until the magnetic bearing is indicated on the pointer and lay one edge on the object to which the bearing was taken. For example, A bears 30° magnetic from an Aircraft. Turn the protractor round until the pointer reads 30, and put one edge on A. A line now drawn from A in the opposite direction from the arrow is the position line.

A fix can thus be very quickly obtained from the intersection of any two lines such as these.

Protractors.—There are a large number of different forms of protractor, and everybody is acquainted with the method of use of this instrument for measuring angles between lines drawn on a plane surface.

One of the most convenient forms of protractor is the Douglas, which is a square of celluloid graduated round the edge from 0° to 360°. The sides are parallel to the 0°—180° and 90°—270° line, and the protractor is divided into a series of ½-in. squares.

One side of the instrument is roughened to permit of the drawing of lines on it. There is a small hole in the centre through which a mark may be made on the map.

The sides of the made square and the 0°—180° and 90°—270° line are divided into tenths of an inch.

As a protractor, its use is quite simple. The parallel lines assist in the setting of the protractor at any point, a suitable line being set parallel to the nearest true or magnetic meridian according as true or magnetic bearing is required.

Parallel lines may be drawn with sufficient accuracy for pilotage purposes by using the edge of the protractor as a straight-edge and setting one of the parallel lines or a pair of the minor divisions along the line to which a parallel is required.

Position may be fixed on a chart or map when the bearings of any two objects have been taken by the following methods.

True bearings of two points A and B having been ascertained to be 30° and 300° respectively, draw lines OA, OB from the centre of the protractor through these divisions on the edge.

Set the protractor north and south by a convenient meridian on the chart and slide it up and down until the points A and B on the chart lie on the lines OA and OB respectively. The centre of the protractor is then your position.

(iii) The Appleyard Air Speed Computer.

A ready means of correcting the air speed of an Aircraft for height is provided by the Appleyard Air Speed Computer, which consists of two circular dials, similar to the time and distance dials on the C.D.I., the inner one of which is capable of revolution, and is graduated from 10 to 250 m.p.h. The outer scale is graduated from 0 to 20,000 ft. Near the zero on the height scale is a " Datum Mark " in the form of an arrow. To use the instrument, set the apparent air speed indicated by the air speed indicator against the height as shown by the altimeter and from the " Datum Mark " read the true air speed.

A rough rule, however, which is quite accurate enough for approximate calculations is add $1\frac{1}{2}$ per cent. to the indicated air speed for every 1,000 ft. of rise in altitude.

(iv) The Card Traverse Calculator.

The initial problem in any flight is to find the course and distance from the starting point to the objective. This can be done by measurement with a protractor and ruler on a map or chart.

It frequently happens, however, that the pilot or observer has no map which shows the two places or that they are shown on different sheets which may or may not adjoin.

The Card Traverse Calculator is an instrument which provides a means of ascertaining the true course and distance between any two points whose position in latitude and longitude is known.

A full explanation of the method of use, which is very simple, is printed on the instrument, so that it is not necessary to give an explanation here.

(v) The Wimperis Course Setting Bomb Sight.

This is an instrument for use in heavy machines, such as a Handley Page or a Vickers Vimy, and is a combined form of C.D.I. and drift indicator, which will calculate accurately course, windage, drift, ground speed and D.R. times.

The principle and method of use is fully described in a pamphlet H. 699, issued by the Technical Department in November, 1918.

CHAPTER VI.

THE AIRCRAFT COURSE AND DISTANCE CALCULATOR.

An instrument known as the Aircraft Course and Distance Calculator provides a simple mechanical means of solving the triangle of velocities.

It is based on the " Battenberg Course and Distance Calculator " used in the Navy.

The latest pattern (9″ C.D.C Mark 1) consists of an outer ring of metal graduated every two degrees from 0° to 360°; 16 of the 32 points of the compass are marked, and every 10° numbered. Inside this ring is a rotating disc of celluloid on which squares, whose sides represent five miles, are marked. The two diameters are marked with a scale of miles every 10 miles from the centre of the disc, the complete diameter representing 240 miles.

Two arms are pivotted at the centre of the disc, each arm being marked at every five miles from the centre on the same scale as the squares. Each arm carries a movable pointer marked A and B respectively, and a central clamp is provided for holding the arms rigid when set.

At the back of the instrument, on the inner circumference of the outer ring and on the rotating circumference of the rotating disc, are marked two scales which form a circular slide rule. These are known as the Appleyard Time and Distance Dials.

From this description it will be seen that the instrument solves the triangle of relative velocities by representing two sides of the triangle by the two sets of parallel lines on the central disc.

Rules for Using the Instruments.—The following rules should be observed when using the instrument:—

(1) " Arm A," when possible, must represent your own course and speed.

(2) " Arm B," when possible, should represent the objective's course and speed.

(3) Always keep the general lines of the situation in your head, remembering that drift is always in a direction away from the wind; this will obviate the possibility of reading from the wrong end.

Example.—To determine the speed and direction of the wind, having observed the path and speed made good—

(*a*) Set arm and pointer A to course steered and air speed.
(*b*) Set arm and pointer B to course made good and ground speed.
(*c*) Set disc so that arrow is parallel to line AB.

Arrow points to direction in which wind is blowing. Length of AB is speed of wind.

Example.—Machine steers 300° at 50 knots. Track observed to be 260° at 70 knots. Find speed and direction of the wind.

(*a*) Set arm and pointer A to 300° and 50.
(*b*) Set arm and pointer B to 260° and 70.

Arrow points to 215°. Length AB = 44.

Answer : Wind blowing from 35° at 44 knots.

Example.—To find what allowance to make for a wind—

(*a*) Set arrow on disc to course to be made good.

(*b*) Set arm and pointer B to direction from which wind is blowing and to speed of wind.

(*c*) Set pointer A to air speed of machine.

(*d*) Revolve arm A till pointer A is on the same line (parallel to arrow) as pointer B.

Arm points to the course to steer.

The distance between pointers A and B will be the ground speed.

Wind N.E., 40 knots. Machine air speed 70 knots. Wishes to make good a track W. What course must be steered?

(*a*) Set arrow on disc to W.

(*b*) Set arm and pointer B to N.E. and 40.

(*c*) Set pointer A to 70.

(*d*) Revolve arm A as in (*d*). (*See* above).

Arm A points to 295°. Length AB = 91.

Answer : Course to steer 295°. Speed along course W. 91 knots.

In addition to the problems discussed above the triangle of velocities is used to find—

(1) The course to steer and the ground speed made good, and direction of the wind and the air speed of the craft.

(2) To determine the speed and direction of the wind, knowing the air speed of the craft, the ground speed and the course made good.

(3) To determine the radius of action of an aircraft.

(4) To determine problems on the interception of aircraft. Examples of these problems are given below as an illustration of the use of the Course and Distance Calculator.

Problem 1.—To find the course to steer and the ground speed made good, knowing the strength and direction of the wind and the air speed of the craft—

Set the arrow on the disc to the course made good. Set arm and pointer " B " to direction from which the wind is blowing and to the speed of the wind. Set pointer " A " to air speed of the machine. Revolve arm " A " till the pointer " A " is on the same line (parallel to the arrow) as pointer " B." Arm " A " points to the course to steer. The distance between the pointers " A " and " B " will be the ground speed.

For example, wind 45° magnetic 40 m.p.h. Track to be made good 270°. Speed of Aircraft 70 m.p.h. Set arrow on the disc to 270°. Set arm and pointer " B " to 45° and 40 m.p.h. Set pointer " A " to 70 m.p.h. Revolve arm " A " until the line joining the two is parallel to the arrow.

Arm " A " now points to 295° and the length " A "— " B " equals 95, therefore the course to steer is 295° and the ground speed will be 95 m.p.h.

Problem 2.—To determine the speed and direction of the wind, knowing the air speed of the craft, the ground speed and the course made good—

(1) Set arm and pointer " A " to the course steered and the air speed.

(2) Set arm and pointer " B " to the course made good and the ground speed.

(3) Rotate disc until the arrow is parallel to the line " A "—" B."

The arrow now points to the direction in which the wind is blowing and the line " A "—" B " is the speed of the wind.

For example, an Aircraft is steering 300° at an air speed of 50 m.p.h.

Track is observed to be 260° and ground speed 70 m.p.h. What is the wind's speed and direction ?

Set arm and pointer " A " to 300° and 50 m.p.h. Set arm and pointer " B " to 260° and 70 m.p.h. Rotate the arrow until it is parallel to a line joining the two pointers, and remember that drift is always in a direction away from the wind.

Arrow points to 215° and the line " A " – " B " equals 45, therefore the wind is blowing from 35° at 45 m.p.h.

Problem 3.—To determine the radius of action of an aircraft—

(*a*) By Problem 1 determine the course out and the course home.
(*b*) Set arm " A " to course out and arrow on disc to course home.
(*c*) Set arm and pointer " B " to total windage.

The line through pointer " B " parallel to the arrow cuts arm " A " at the turning point, *i.e.*, the distance through the air.

For example, find the radius of action of an Aircraft in a direction N.E. (45°) True, given that—

Air speed is 60 m.p.h. Wind 337° (True), 20 m.p.h. Fuel capacity five hours.

(1) By Problem 1, course out is 27°, 50 m.p.h., and course home is 242°, 64 m.p.h.

(2) Set arm " A " to 27, and the arrow to 242°.

(3) Set arm and pointer " B " to 337°, and 100 (it is necessary here to divide the scale by 2. Set pointer " B " to 50), when a line through " B " parallel to the arrow cuts " A " in 88, *i.e.*, 176 ; the time to turn will therefore be $\frac{176}{60}$ = 2 hrs. 56 mins.

Since ground speed out was 50 m.p.h., the distance covered can be found from the time and distance scale, *i.e.*, 146 miles.

Problem 4.—Interception of Aircraft.

There are two cases of interception—

(1) When the course and air speed of the craft to be intercepted are known.

(2) When the track and ground speed of the craft are known.

(*i*) Course and air speed of craft to be intercepted are known.
- (*a*) Set the arrow on the disc to the bearing of the objective.
- (*b*) Set arm and pointer " B " to the course and speed of the other Aircraft.
- (*c*) Set pointer " A " to the air speed of machine.
- (*d*) Revolve arm " A " until the pointer is on the same line parallel to the arrow as pointer " B."

Arm " A " points to the course to steer and the distance AB is the speed of approach, and the time to intercept will be distance off divided by AB.

Example : An Aircraft is reported bearing 45°, 120 miles away, steering 270° at 60 m.p.h. Your air speed is 100 m.p.h.

(*a*) Set the arrow on the disc to 45°.
(*b*) Set arm and pointer " B " to 270°, 60 m.p.h.
(*c*) Set pointer " A " at 100, and revolve arm " A " until pointer " A " is on the same line parallel to the arrow as pointer " B."

Arm " A " points to course to steer 20°, and AB 134 is the speed of approach. Time of intercept is found from the scale, *i.e.*, 53½ min.

(ii) Track and ground speed of craft to be intercepted are known.

The simplest way of solving all problems where three velocities occur, *i.e.*, windage, objective, and your own, is to reduce them to two by resolving the windage and your objective into one.

This is done by considering the wind to have the opposite effect on your objective to what it would have on you, *i.e.*, you find the course steered and air speed of your objective and then proceed to intercept as in Case 1.

Example : An Aircraft is reported at 18.00 to be passing over a place A. At 18.30 it is reported to be over B which is 25 miles due 270° of A. B bears 45° and is distant 120 miles from you. Your air speed is 70 m.p.h. and the windage is 315°, 20 m.p.h. Required to find course and time of intercept.

(*a*) Set arm and pointer " A " to 270° and 50 m.p.h. (the objective's ground speed.)

(*b*) Set arm and pointer " B " to 135° and 20 m.p.h. (windage reversed).

Revolve the disc until a line parallel to the arrow passes through the two pointers, and the arrow points to 283° and distance BA is 66.

Now set arm and pointer " B " to 283° and 66.

Set arrow to 45° and pointer " A " to 70.

Revolve arm " A " until pointer is on the same line parallel to the arrow, as pointer " B " and arm " A " points to 353°. Length of AB is 78.

Course to steer is 353° and time taken is 1 hr. 32 mins.

All these examples should be worked out on the actual instrument itself, so that its use can be thoroughly understood.

In working with the C.D.I. all problems involving the triangle of velocities can be solved, but it nearly always happens in practice, that, except in the simplest cases, a proportion sum has to be worked out to complete the solution. There is no mathematical difficulty in this, but the pilot is generally pressed for time and is apt to make mistakes, especially if a mental calulation is attempted. For this reason the Appleyard Time and Distance Dial, which is a circular slide rule, has been fitted to the Calculator and comprises an inner fixed time dial in the circumference of the instrument itself, and an outer rotary distance dial on the circumference of its own disc, which is concentric with the former.

On the latest pattern the above arrangement has been reversed, the time dial rotating and the distance dial remaining fixed. This addition gives the required solution in time, distance or speed.

Method of using Time and Distance Dial.—The following three examples will help the working of the dials to be understood.

1. **Time.**—The ground speed of an Aircraft is found by the Calculator to be 47 knots, the distance of the objective is 112 nautical miles. What will be the time taken to reach the objective.

Set 47 knots on outer scale over 60 minutes on inner scale and under 112 miles on outer scale read 143 minutes on inner scale.

Answer : Time—2 hrs. 23 mins.

2. **Speed.**—The distance of an objective is 128 nautical miles. What speed must an Aircraft make good to reach it in 96 minutes ?

Set 128 miles on outer scale over 96 minutes on inner scale and over 60 minutes on inner scale read 80 knots on outer scale.

Answer : Ground speed 80 knots.

3. **Distance.**—An Aircraft has made good 67 knots for 2 hrs. 8 mins. What distance has it covered ?

Set 67 knots on outer scale over 60 minutes on inner scale and over 128 minutes on inner scale read 143 miles on outer scale.

Answer : 143 nautical miles.

To convert knots (sea miles) to statute miles or *vice versa*.

10 knots=11·5 miles.

How may statute miles=70 knots ?

Set 10 knots on outer scale over 11·5 miles on inner scale and under 70 knots on outer scale read 80·5 miles on inner scale.

SOME FURTHER PROBLEMS ON LAYING OFF COURSE BY PLOTTING.

1. **Interception.**—In all problems dealing with the interception of Aircraft, the effect of the wind may be disregarded, since both aeroplanes are equally affected thereby.

An Aircraft C is steering W. (270°) at an air speed of 65 m.p.h. and is distant 60 miles on a bearing of 30° from A.

It is required to find the course to be steered by an Aircraft having an air speed of 70 m.p.h. in order to intercept C.
Fig. XXI.

From A lay off AC bearing 30°, and 60 miles to scale, then C is the position of the craft to be intercepted. Lay off 270° from C.

It must now be imagined that a wind is blowing exactly opposite in direction and velocity to C's course, *i.e.*, 90° at 65 m.p.h.

In this case C is stationary, and therefore A has to make good the track AC.

From A lay AB 90° and 65 miles to scale, and with B as centre and radius 70 m.p.h. describe an arc cutting AC in E. Join BE.

Through A draw AD parallel to BE cutting CD in D.

Then AD is the course to steer (336°).

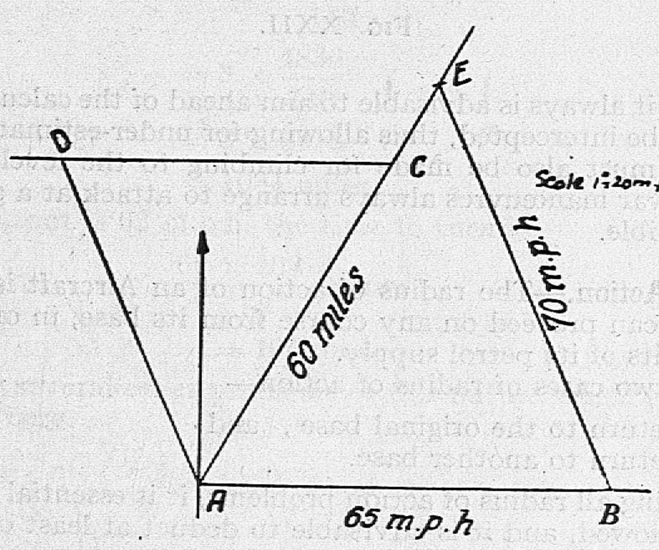

Fig. XXI.

2. Interception of ships, troops, convoys, etc., moving on sea or land FIG. XXII.

A vessel C is distant 40 miles from B bearing 20° and making good 135° at 20 knots.

The wind is E (90°) at 20 knots.

Find the course and time taken to intercept by an Aircraft whose air speed is 60 knots.

FIG. XXII. From B lay off BC—20° and 40 miles to scale. Then C is the position of the vessel to be intercepted. From C lay off CX 135°, the direction C is making good.

From B draw BD parallel to CX and 20 knots to scale 315°.

From D lay off DE—the windage 270°, 20 knots.

From E describe an arc of radius 60 knots, to cut BC produced in K. Join DK, and lay off BM parallel to DK, cutting CX at M.

Then EK is B's course 58° to intercept C at M, BM is B's track and DK is ground speed—44 knots.

$$\text{Then}\ \frac{\text{BM in miles}}{44} = \text{time taken to intercept,}$$

$$i.e.\ \frac{36}{44} = 49 \text{ minutes.}$$

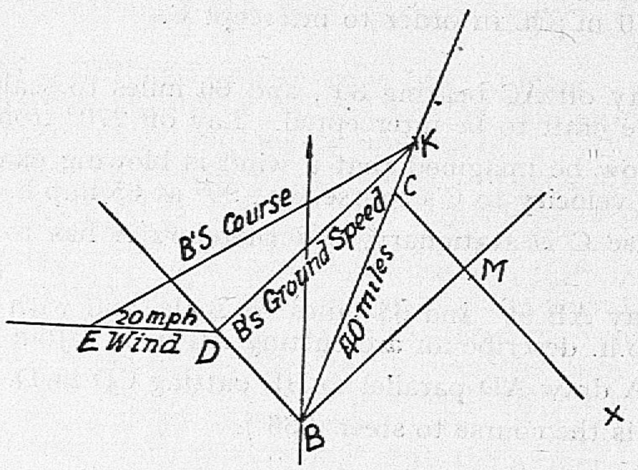

FIG. XXII.

In practice it always is advisable to aim ahead of the calculated position of the craft to be intercepted, thus allowing for under-estimation of speeds.

Allowance must also be made for climbing to the level of the other craft, and in war manœuvres always arrange to attack at a greater height whenever possible.

Radius of Action.—The radius of action of an Aircraft is the distance that the craft can proceed on any course from its base, in order to return within the limits of its petrol supply.

There are two cases of radius of action—

(i) To return to the original base ; and
(ii) To return to another base.

In calculating all radius of action problems, it is essential that a margin of safety be allowed, and it is advisable to deduct at least one hour's fuel from the petrol hours employed.

(i) Returning to the same base.

This problem can be solved by White's formula—

$$R = P \times \frac{\text{ground speed out} \times \text{ground speed in}}{\text{ground speed out} + \text{ground speed in.}}$$

Where R = Radius of action, and P = petrol hours.

Ground speed out and in can be found by laying off course to allow for windage and applying the formula.

This formula is proved in the following way:—

Let T = Time out. Let X = Speed out.

Let T1 = Time home. Let Y = Speed home.

Then P (petrol hours) = T plus T1.

R (radius of action) = T × speed out, and also = T1 × speed home.

$$\therefore P = T1 = \frac{R}{X} + \frac{R}{Y}$$

$$\therefore P = R\left(\frac{1}{X} + \frac{1}{Y}\right)$$

$$\therefore P = R\left(\frac{Y + X}{X \times Y}\right)$$

$$\therefore R = P \times \frac{X \times Y}{X + Y}$$

Example: An Aircraft carries four hours' petrol, and has an air speed of 70 m.p.h.

Find its radius of action in a direction N.E.(45°) in a wind of 20 m.p.h. from 110°, by plotting.

By using the C.D.C.—

Course out is found to be 62°, and ground speed 62 m.p.h.

Course in is found to be 208° and ground speed is 78.

$$R = P \times \frac{\text{G.S. out} \times \text{G.S. in}}{\text{G.S. out} + \text{G.S. in}}$$

Deduct 1 hour for margin of safety.

$$R = 3 \times \frac{62 \times 78}{140}$$

$$= 3 \times \frac{4836}{140}$$

$$= 3 \times 34{\cdot}5$$

$$= 103\tfrac{1}{2} \text{ miles.}$$

Since G.S. out is 62 m.p.h. the time to turn is—

$$\frac{60 \times 103{\cdot}5}{62} \text{ mins.}$$

$$= 100 \text{ mins.}$$

There are several other problems of this nature which it is unnecessary to deal with here.

CHAPTER VII.

BEARINGS.

Bearings and Fixing Position by Bearings.—It has already been shown in Chapter I, Section II, how a position on the Earth's surface is determined by latitude and longitude; it is now necessary to consider how to determine the direction of one position from another.

The direction of any point on the surface of the Earth from an observer is known, if the angle at the observer between his meridian and the great circle passing through the observer and the point is also known.

True Bearing.—This angle is known as the True Bearing or Azimuth of the point, and is measured north or south towards east or west from 0° to 90°, or it may be measured from north, clockwise from 0° to 360°.

A true bearing may be found either by means of a magnetic or gyroscopic compass or by astronomical methods.

Compass Bearing.—The compass bearing of an object is the angle from the compass needle to the direction of the point on the Earth directly under the object.

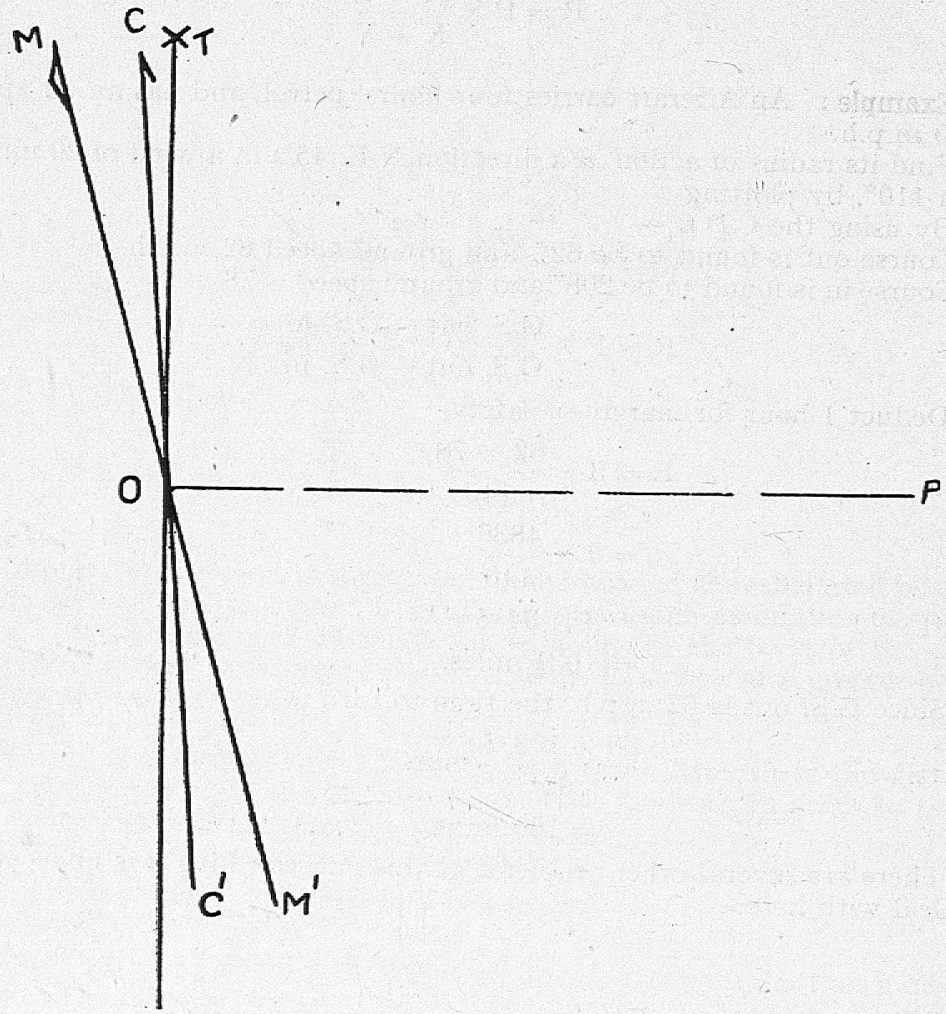

FIG. XXIII.

Magnetic Bearing.—The magnetic bearing of an object is the angle from the magnetic meridian to the direction of the point on the Earth directly under the object.

The majority of bearings will necessarily be taken with a compass or bearing plate, and therefore deviation and variation must be applied in order to obtain the true bearing.

FIG. XXIII.

The True Bearing of P from O is angle TOP.
The Magnetic Bearing of P from O is angle M′OP (variation 15° W.)
The Compass Bearing of P from O is angle C′OP (deviation 5° W.)

It must be remembered that when correcting variation, deviation and compass error, add if easterly and subtract if westerly.

Note.—A true bearing is obtained from a compass bearing by applying the compass error, which is the sum or difference of deviation and variation.

Fixing Position by Cross Bearings.—Fig. XXIV illustrates the method of fixing your position by taking bearings on three visible objects.

An observer at O, whose position is unknown, can see a lighthouse L, a tower T, and a flagstaff F. By means of a compass a bearing is taken on each of these three objects.

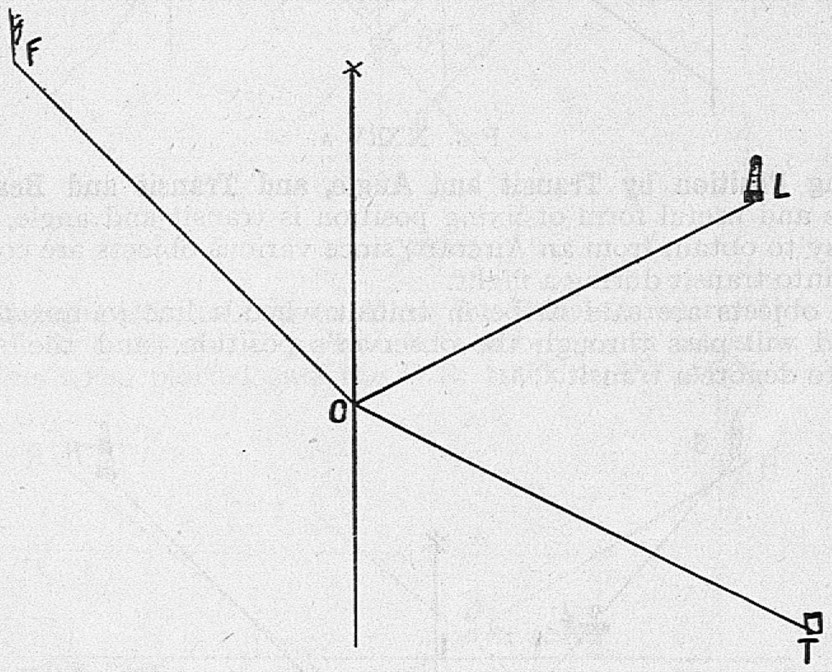

FIG. XXIV.

The deviation is known to be 4° E., and the variation 15° W. The bearings obtained were—

L. 63°
T. 117°
F. 316°

Having applied compass error, the three position lines are laid off on the chart or map as back bearings from the objects, and the point where they intersect is the observer's position at that particular time.

It is important to note the exact time at which any bearings are taken, since in an Aircraft, ship, or other moving body, the position obtained is that at the time the bearings were taken, and an error of several minutes may mean that the fix obtained is incorrect.

A position can always be fixed by two or more cross bearings.

Compass Bearings.		*True Bearings.*		*Back Bearings.*
T. 117° — 11° Compass Error	..	106° + 180°	..	286°
L. 63° — 11° Compass Error	..	52° + 180°	..	232°
F. 316° — 11° Compass Error	..	305° — 180°	..	125°

In the event of the three bearings not intersecting in the same point, as is nearly always the case in practice, owing to errors in taking bearings, the centre of the triangle thus formed is considered to be the fix.

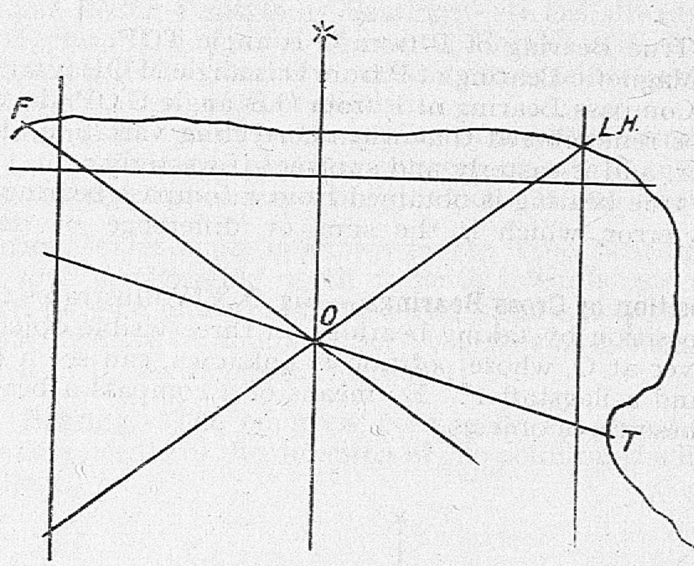

FIG. XXIV A.

Fixing Position by Transit and Angle, and Transit and Bearing.—A valuable and useful form of fixing position is transit and angle, and it is very easy to obtain from an Aircraft, since various objects are continually coming into transit during a flight.

Two objects are said to be in transit when a line joining them and produced will pass through the observer's position, and the symbol ø is used to denote a transit.

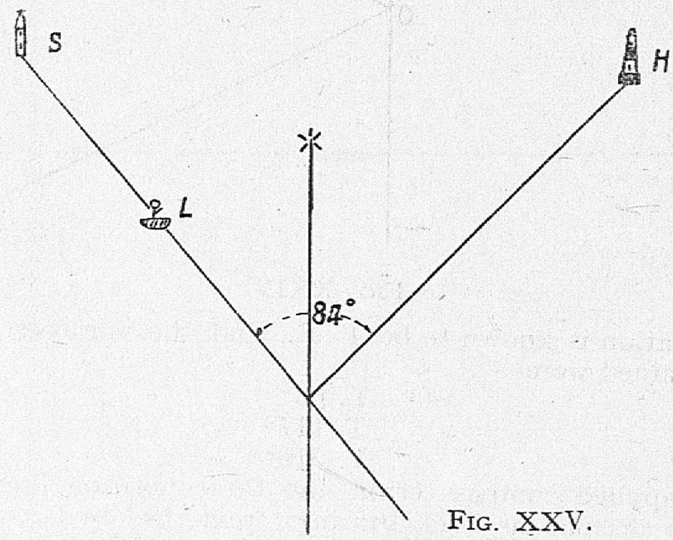

FIG. XXV.

Thus A ø B indicates that A, the nearer object, is in transit with B, the more remote.

In order to fix a position by this method, choose two objects in transit and take an angle to a third object.

FIG. XXV.—Light vessel L ø Steeple S., 84° Lighthouse H.

Join the two objects in transit, and from any point A in this line lay off an angle of 84° AC. Run a line parallel to this line AC through the third object, and where this cuts the line of transit is the fix.

If more convenient a bearing of the third object can be taken and converted to true or magnetic and laid off as above.

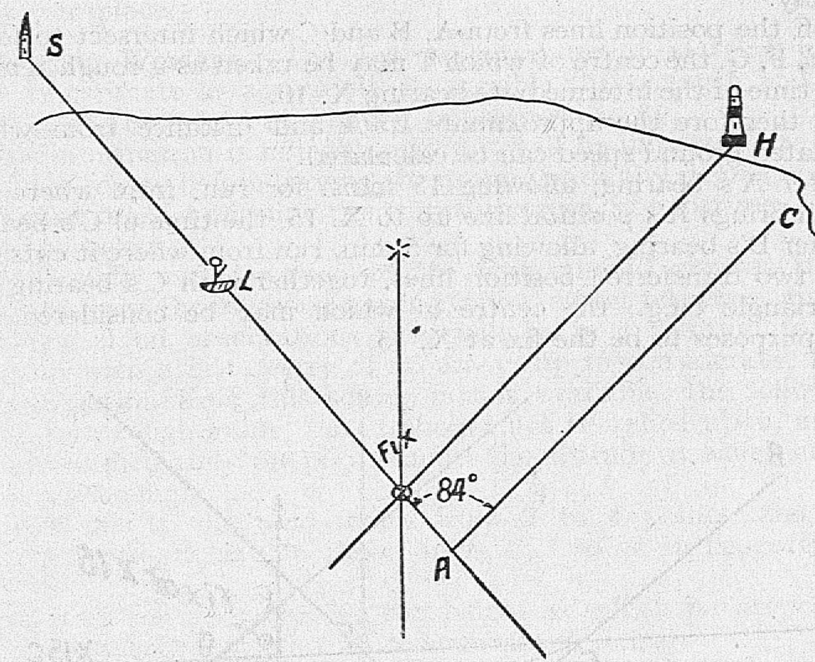

FIG. XXVI.

Transfering Position Lines to Allow for Run.—An Aircraft is making good the D.R. track of TT′ and at X.O. a bearing is taken on A. This position line when plotted cuts the D.R. track at P. At X 5 a bearing

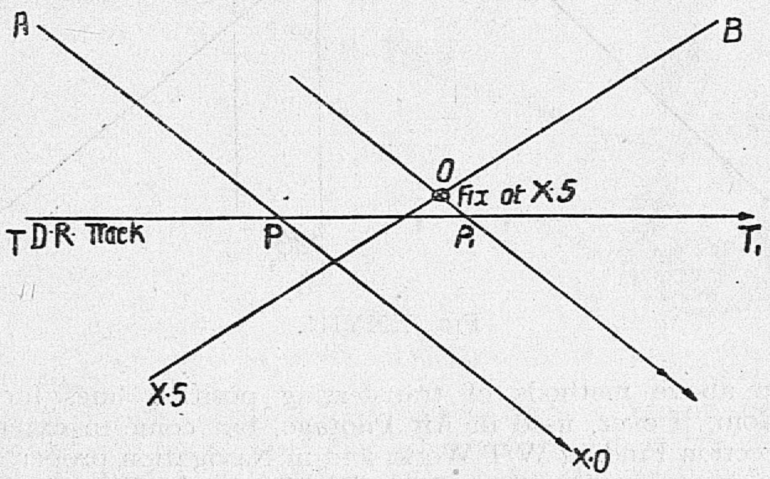

FIG. XXVII.

is taken on B. Calculated from D.R. ground speed, the run in 5 mins. is to P′. If a line parallel to A.P. is drawn through P′, *i.e.*, the position line from A is transferred allowing for run, it cuts the position line from B in O, which is the fix at X 5.

It is a very good plan to show position lines with a single-headed arrow, and transferred position lines with a double-headed arrow.

In the case of obtaining three position lines with a short interval of time between each bearing, the procedure is as follows :—

Fig. XXVIII.—Let D be the departure point, and A, B and C three fixed points from which bearings are taken at X. 05, X. 10 and X. 15 respectively.

Lay off the position lines from A, B and C which intersect to form the triangle E, F, G, the centre of which T may be taken as a rough temporary fix at the time of the intermediate bearing X. 10.

DT is therefore the approximate track and distance from which an approximated ground speed can be calculated.

Transfer A's bearing, allowing 15 mins. for run, from where it cuts DT, which brings A's position line up to X. 15, the time of C's bearing.

Transfer B's bearing, allowing for 5 min. run from where it cuts DT.

These two transferred position lines, together with C's bearing form a smaller triangle e.f.g., the centre of which may be considered for all practical purposes to be the fix at X. 15.

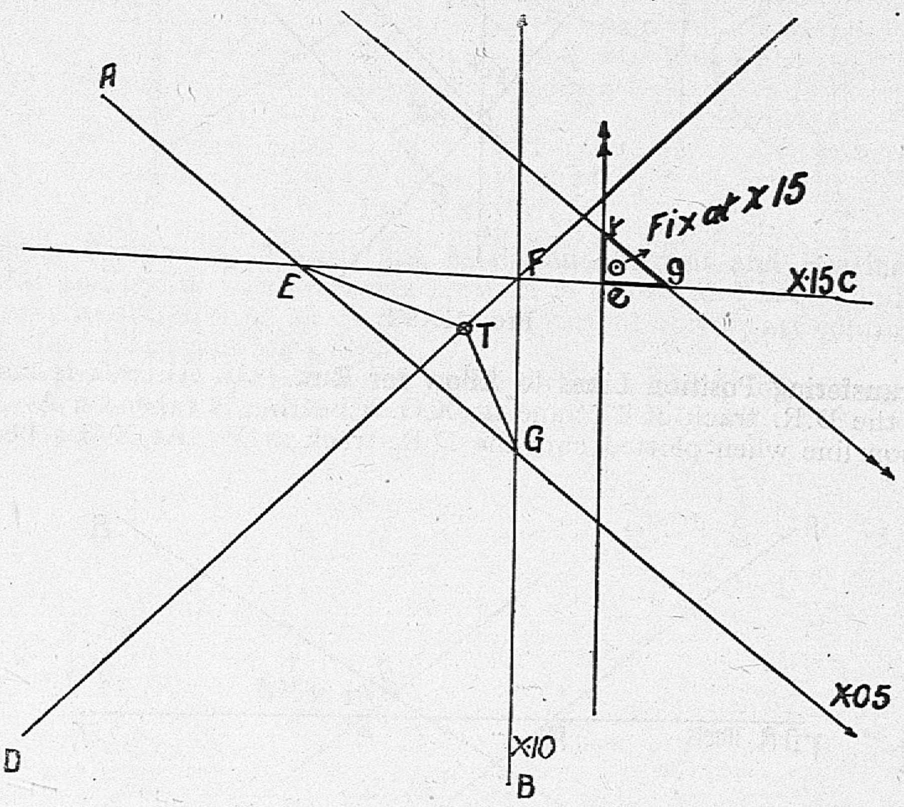

Fig. XXVIII.

Note.—The above methods of transferring position lines for run are seldom, if ever, used in Air Pilotage, but come in extensively in Direction Finding W/T Work, and in Navigation proper.

It is, however, possible that they might be required when over the sea within sight of land or light vessels, or in badly mapped country such as Syria, where the visibility is so good that objects distant 50 miles can frequently be easily distinguished, and therefore it is necessary for these methods to be understood.

CHAPTER VIII.

PRACTICAL AIR PILOTAGE.

In this chapter it is intended to deal with the practical application of the instruments, etc., previously discussed, to piloting an Aircraft from place to place.

Calculating Windage.—The first essential before starting on a long flight is to estimate as accurately as possible the strength and direction of the wind at the height at which it is proposed to fly.

If this information is not obtainable it will be impossible to work out the compass course before leaving the ground with any degree of accuracy, and the pilot must determine the course to steer by experiment in the air as described below.

The strength and direction of the wind should always, if possible, be obtained from the Meteorological Station, as by releasing air balloons and making cloud observations they will be in a position to give this information with a fair decree of accuracy, up to considerable heights.

If information from this source is not available, the following may be taken as a rough guide, but it should not be relied upon, and should be checked immediately the pilot reaches the altitude at which he proposes to carry out the flight.

Up to 5,000 ft. the wind veers from 2 to 4 points, and generally increases in strength two to three times, and so on in proportion to the height.

As soon as the pilot reaches the height at which he proposes to fly, the Aircraft should be settled on the estimated course.

The pilot then observes some point (which should previously be fixed from the map before starting), in the line of flight, and notes the time the Aircraft passes over it. After flying for 10 or 15 min. the position is fixed at A, Fig. XXIX.

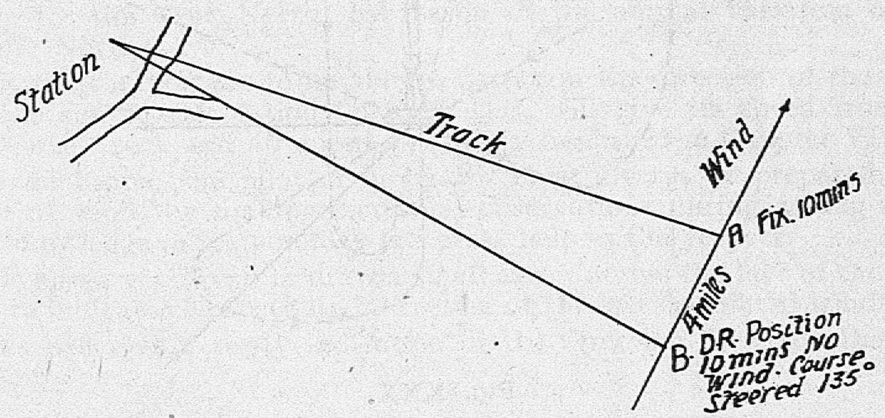

Fig. XXIX.

If there had been no wind the position at the time of the fix would have been B (calculated from the air speed, which is the same as the ground speed when the windage is nil). Since the position was fixed at A, BA must be the direction of the wind, and if the distance B to A is four miles, the speed of the wind must be four miles in 10 min., *i.e.*, 24 m.p.h.

The above method of calculating the windage can be worked on and plotted very simply on the Bigsworth Chart Board, and is one of the easiest methods.

The second method is by the use of leading marks a known distance apart, on a known bearing. If these two leading marks are joined by a straight road or railway track it is a great help.

The Aircraft is flown so that it passes over these leading marks, the time taken to run between the marks being noted.

The course and air speed are known, and the track is the bearing of the leading marks.

The time for the run will give the ground speed, and from these four factors the windage is calculated on the C.D.C.

There is another method which is useful when flying over unmapped country or over the sea, when only one fixed object is visible, which is to alter course on the Aircraft until it is flying head to wind.

For example (FIG. XXX), an Aircraft is over the sea, the only fixed object visible being a light vessel. Course is shaped to pass over this, and the pilot notes that the Aircraft is steering 100°, and drifting towards the south.

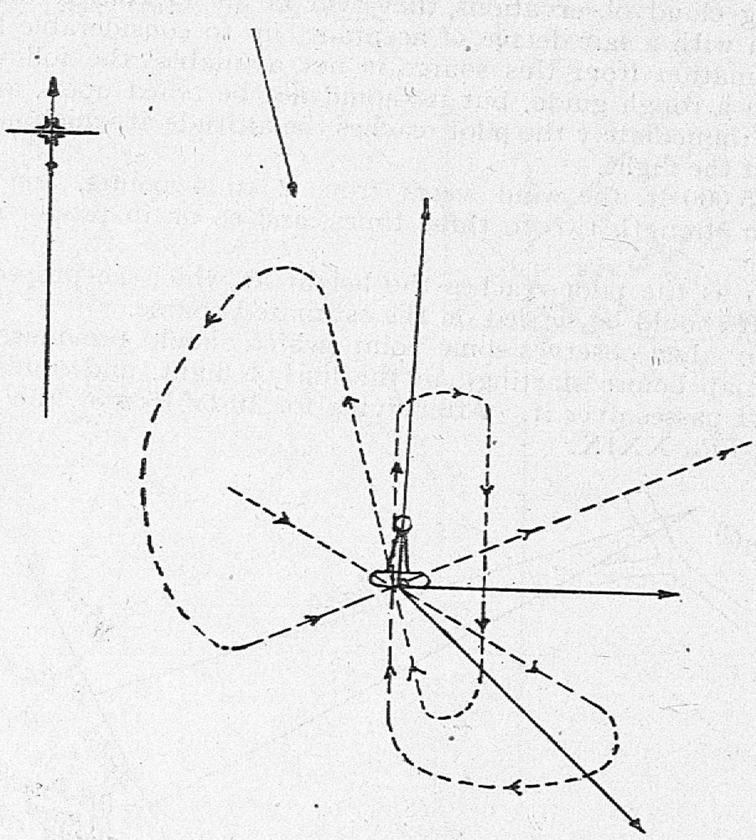

FIG. XXX.

As the machine passes over the light vessel, this drift is measured by means of the drift indicator and found to be 15° to starboard.

From this the pilot assumes that the wind is blowing from the north, and altering course accordingly again flies over the light vessel steering north. This time the drift is noted as being 5° to starboard, which shows the wind to be west of north.

It will thus be seen that by a careful process of elimination, the pilot can steer the machine into the wind, finally passing over the light vessel with no drift at all.

The final course is found to be 339°, which must be the direction of the wind. The pilot now alters course 90° and steers 69°, again flying over the light vessel and noting the drift.

This time it is found to be 20° to starboard.

The following data are now available.

Air Speed 70 m.p.h. ..	Final Course 69°.
Final Track 89°	Direction of Wind 339°

A simple calculation on the C.D.C. will now give the velocity of the wind.

Set the arrow to the track.
Set arm A to the direction of the wind.
Set arm B to course.
Set pointer B to air speed.

Then where the line through B parallel to the arrow cuts arm A, is the speed of the wind = 25 m.p.h.

Another useful method of obtaining the windage prior to a flight, when there are detached clouds in the sky, is as follows :—

First of all judge roughly the height of the clouds and the speed at which they are travelling.

This requires experience, but can quickly be learnt.

Take an Aircraft which is standing on the Aerodrome, note the direction of its head from the compass, and set the plate of the drift indicator in this direction.

Then stand with the head immediately under the indicator and move the wires until a cloud passes straight along them.

The bearing must then be corrected for variation and deviation to give the true direction of the wind and the height and speed having all ready been estimated, the full particulars are now available.

It is usual, as has already been shewn in Chapter II, to convert all Compass Bearings to True, since all Charts and Maps are constructed relative to the True North, by reason of the annual variation of the Magnetic North.

It is most important to be able to ascertain the direction of the wind, since the simple calculation on the C.D.C. will give its speed from the data course, track and air speed as already described in Chapter VI.

In conclusion, the pilot or navigator must always be prepared for a change of wind, by making continual observations during a long flight, and a knowledge of meteorology is a great help in this respect.

It is also a good plan to draw a small arrow across the face of the chart board to indicate the speed and direction of the last calculated windage.

This will give a ready indication of the direction in which the craft is drifting.

Laying Off Course.—In order to accurately lay off a course, the following information is essential.

(1) The Air Speed of the Machine.
(2) The Force and Direction of the Wind (Windage).
(3) The Track.
(4) The Distance.

(1) This is read from the Air Speed Indicator in the machine. It must be remembered, however, that the readings of this indicator are affected by height, and a table should therefore be fixed to the dashboard as close to the Air Speed Indicator as possible, showing in one column the height

and in the other the actual air speed. This is easily calculated by allowing an increase of $1\frac{1}{2}$ per cent. on the indicated reading for every 1,000 ft. of height.

(2) **Windage.**—This should be obtained, if possible, from the Meteorological Station; failing this, it may be roughly estimated as described earlier in this chapter. In any case it must be checked as soon as the machine has arrived at the height at which the flight is to be carried out.

(3) (4) The track and distance must be laid off on the chart or map before commencing the flight.

When starting out on a cross-country flight, first get the necessary maps or charts and then set them up in the Bigsworth Chart Board, so that the proposed route is covered. Then join the departure point and the objective, and measure the track and distance. Next calculate the course and ground speed on the C.D.C. and work out the D.R. time for the objective. Now mark off along the track those places, or prominent objects, that it is considered will make good D.R. positions for checking the run, and measure their distance from the departure point, calculating the D.R. time for each by means of the outer ring on the C.D.C. Mark this D.R. time plainly alongside each place on the track. Finally draw a small arrow at the top of the board to indicate the direction from which the wind is blowing, at the height at which it is proposed to fly.

If, as may often be the case, the proposed flight extends over two or more sheets of map, the track, etc., should be drawn and worked out on the map before it is inserted in the Bigsworth Chart Board. It can easily be changed over in the air, and then as each sheet comes along the track, etc., will be already laid off.

There is another important point, in connection with the windage, which should be studied before beginning a cross-country flight. The wind, as has already been explained, varies in strength and direction at different heights. Therefore the reports of the wind in the upper air should be studied with a view to taking advantage of the most favourable.

For example, a pilot, who is proposing to carry out a cross-country flight, works out his track to be 45°.

The meteorological reports give the following wind readings :—

1000′	15 m.p.h.	200°
2000′	17 ,, ...	217°
3000′	8 ,, ...	230°
4000′	14 ,, ...	235°
5000′	21 ,, ...	220°

Therefore the best track will be made by flying at 5000′, which will give practically a following wind of 21 m.p.h.

The pilot or observer should always be careful to arrange the work in his notebook clearly, so that there will be no chance of confusion or misunderstanding during the flight.

For example :—

ANDOVER—HOUNSLOW.

Track	Distance.
Air Speed	Windage.
Course	Height.
Ground Speed ..	D.R. Time.
D.R. Positions ..	D.R. Times.

It is very important to check the position of the Aircraft as often as possible, and for this purpose a fix should be obtained frequently during the flight, whenever a suitable opportunity presents itself. This is especially important if part of the flight is over the sea, or in or over clouds. In this case it is essential that a fix be obtained before losing sight of the ground, because this means that the pilot has then some definite fixed point to work from when he next gets an opportunity of taking another fix, and unless the wind has suddenly increased to gale strength, the Aircraft should not be more than 10-15 miles off its course, after even 30 minutes from the last fix.

The whole question bears on the drift, and so long as the pilot keeps in mind the direction in which he is being drifted, no difficulty should be experienced in picking up the course again.

Night Navigation.—The pilot of a machine flying at night has to depend on lights for fixing his position, and therefore a careful study of the lights shown by the various places, at various times, throughout the night must be made. Each town, big railway station, port or dockyard has its own peculiarities in the disposition of its lights, and must be recognised by the shape of its lights, in the same way that it is recognised by its shape during the daytime. The recognition of lights is a matter of experience, and pilots and navigators passing over a district for the first time should take notes of the appearance of various towns, and try to photograph them on their memory for comparison with a map.

A few striking examples in the South of England are, Eastleigh, where the lights of the locomotive sheds to the south-east of the town represent a rather elongated " pair of wings." Southampton where the arc lamps of the dockyards give an outline of the shape of the docks and the head of Southampton water, with the town immediately north of them, and Portsmouth and Gosport where the shape of the land is again outlined by the lights.

Very careful dead reckoning must be kept at night, and positions fixed as often as possible.

It is much easier to steer a steady course at night as few bumps are encountered, and by exercising care and relying on his dead reckoning, the pilot should always be able to bring his Aircraft to within sight of the lights of each D.R. position.

Drift should be checked frequently, and the machine kept to her track by this means. A single light is sufficient to give an observation of drift, and the drift wires, being luminous, can be seen on the darkest night, while the light of an electric torch is sufficient to read the figures on the bearing plate.

The calculation of windage at night offers a certain amount of difficulty, unless two lights on a known bearing and a known distance apart are used, when the ordinary two point method will give a reasonably accurate result.

Alteration of windage during a flight must be carefully calculated from dead reckoning. The run between fixes, and the course and drift will enable this calculation to be made.

Fixing Position by Bearings.—The bearing plate or " Pelorus " should be used at night as an aid to fixing position, and although its use presents some difficulty to the inexperienced pilot, it can, if used with care and a little thought, help to establish position within a few miles.

For example (Fig. XXXI), the Aircraft P is navigating to make good the Track P-T, and by his D.R. the pilot knows that he [should pass the lights of B and the lights of A to port, while his track passes over a dark area.

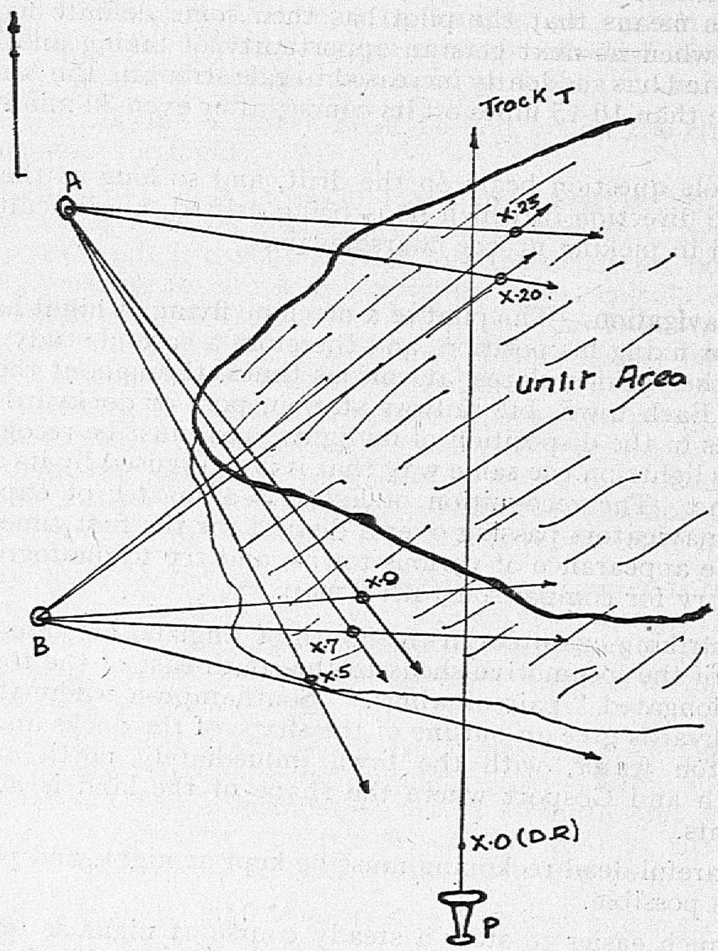

Fig. XXXI.

If he judged his distance from A and B by eye, it would obviously be impossible to say whether he was anywhere near his track; if the night was clear and the lights A and B powerful he might be 10 or 15 miles out.

Instead of trusting to eye he fixes his position with the bearing plate in the following way :—

At X.0 o'clock he sights B on the port bow, and according to his D.R. he should be at X on his track.

At X.5 B is abeam, and A is in sight. As quickly as possible he reads off two bearings on to A and B respectively, with an interval of a few seconds only between. He notes these down. "X.5, B.290°. A.335° Mag."

At X.7 he repeats this, and at X.9 also, obtaining the following readings:

X.7 ..	B.274° ..	A.328° Mag.
X.9 ..	B.268° ..	A.325° Mag.

It is most important to note the time of the bearings.

When these bearings are laid off on the Bigsworth Board, the three fixes shown will indicate that a track parallel to the D.R. track is being

made good, and although they will not fix the position accurately, since there are bound to be errors in the sights taken, they will give an indication of the locality to within five miles. Some ten minutes later the pilot again takes a couple of bearings as quickly as possible on A and B, and notes down the following results :—

X.20	B.235°	A.280° Mag.
X.23	B.233°	A.275° Mag.

On plotting these out the positions shown are obtained, which gives the pilot the information that the track he has made good during the last ten minutes is to the eastward of his D.R. track, and therefore he must alter course slightly to port in order to run on or parallel to the required track.

Lighthouses and light vessels are very useful for fixing position when flying near the coast, and a careful study of the coastal charts must be made previous to any flight near the sea, so that the lights are recognised.

Lighthouses and vessels are visible from 10 to 20 miles, and the reflection of the beams of their light on the water can be plainly seen.

Land lighthouses are in use for the guidance of the pilot at night, in the same way as the lighthouse guides the mariner. Their exact location and the letter or flash they give must be known, so that they can be used for fixing position.

In the Air.—The following description of the navigation of an Aircraft on a long distance flight will illustrate the practical application of the foregoing principles.

The maps referred to are sheets 8 and 9 of the Ordnance Survey, 4 miles to 1 inch, and the flight described is from Stonehenge to Westward Ho, the Aircraft being a D.H.4. The Aircraft was timed to start at 11 a.m. and the weather was fine, with large banks of cumulus cloud at heights from 2,000 to 5,000 ft. The 10 a.m. meteorological report and pilot balloon ascent gave warning of low cloud in the West of England and the following windage :—

1000 feet	15 m.p.h.	275°
2000 ,,	17 ,,	257°
3000 ,,	18 ,,	280°
4000 ,,	21 ,,	234°
5000 ,,	23 ,,	241°

It was agreed to fly at 4,000 ft., and the pilot made the following calculations :—

	Track 282° Mag.	Distance 105 miles.
Air Speed	100 m.p.h.	Windage 21 m.p.h. 249° Mag.
Course.	274° Mag.	Ground Speed 82 m.p.h. D.R. Time 77 min.

D.R. Positions	Distance	D.R. Times.
1. Railway W. of Upton Lovel	11m.	8 mins.
2. Deverill	15m.	11 ,,
3. Glastonbury	38m.	28 ,,
4. Bridgwater	50m.	36½ ,,
5. Road and Railway 1 mile S. of Crowcombe	60m.	44 ,,
6. Barnstaple	95m.	70 ,,
7. Westward Ho	105m.	77 ,,

The Aircraft left the ground at XI.0 a.m. and circled round the aerodrome climbing to 4,000 ft. At XI.5 course was set to 276° compass (the deviation on west being 2° W), when over the aerodrome.

The navigator noted in his log: "Left XI.5 a.m. Course was 276°. Height 4,000. Air speed 100 m.p.h.," and at once took the drift from objects below, with the drift indicator. This he observed to be between 8° and 10° to starboard, which was correct. He checked his drift several times during the first ten minutes, and found that the mean drift was correct, and that at XI.13 the Aircraft was over the first D.R. position. He informed the pilot that the course was correct, and checked the ground speed by the run between the first and second D.R. positions, a distance of four miles, which was covered in 2 mins. 45 secs. giving an increase of ground speed to 87 m.p.h. He made a mental note that the next D.R. position would appear a little before D.R. time, and marked the fixed position at XI.16. Satisfied that the Aircraft was on her course he put instruments away, and made a note that his next D.R. position, Glastonbury, should appear on the starboard bow in about 15 minutes time. The Aircraft passed through several patches of cloud here, and visibility became very poor.

At XI.28 Glastonbury came in sight, at an angle of some 30° off the head, and it was obvious that the Aircraft would pass about two miles south of the town. At this moment she entered a big cloud, and the navigator fixed the position and time of entry into cloud at Butleigh Wootton XI.30 two miles south of track and three minutes ahead of D.R. time. At XI.36 the cloud was penetrated, and the pilot having decided to descend to 3,000 ft., the navigator observed Bridgwater about four miles on the starboard side. He checked the drift from passing objects and found that it was now only 5° to starboard. He decided to make a small alteration of course and wrote on a pad of paper "Steer 282°," gave his rudder bar a slight kick to attract the pilot's attention and held up his writing-pad. The pilot altered course as directed, and the navigator logged the following :—

"XI.36 fix 4 miles S. of D.R. Drift 5° starbd a/c 282° height 3,000."

Heavy clouds were now approaching, and five minutes after this the navigator fixed position 1 mile S. of the Wood at Crowcombe, and directed pilot to steer 280°, entering in the log "XI.41 fix 1 mile S. Wood Crowcombe a/c 280°."

Clouds became very thick here, and it was impossible to fix position or check drift. The pilot shut off the engine to descend, but the navigator warned him of the high ground over Exmoor, and he then climbed to 6,500 ft. where clouds were penetrated, and a clear sky was found with clouds beneath. The navigator entered the following in the log "XI.50 climbed to 6,000 ft., course 280°, estimated position over Brendon Hills, clouds below."

At XII.0 noon the clouds became detached, and the navigator at once endeavoured to fix the position. From the calculated ground speed 87 m.p.h. and run since the last fix at XI.41 he estimated position to be about North Molton, and looked for the village with the C-shaped wood to the north. This was not to be seen, but almost immediately below was a straight railway running in a N.W. direction, with a road on the south side of it. The country was very open and a fix was difficult, but when drift was found to be nil, it was obvious that the Aircraft must be to the south of her track, and that the railway was leading into South Molton. This was confirmed at XII.2 when a fix was made at South Molton. The navigator accordingly directed the pilot to alter course to 285°, which gave a drift of 4° to starboard, and thus a track of 287° magnetic. Clouds had cleared by this time, and at XII.5 the sea and Bideford became visible, the aerodrome at Westward Ho being made at XII.14.

CHAPTER IX.

PRACTICAL NOTES.

1. Always look after the compass. Have it swung frequently and see that the deviation card is kept up to date and put where it can easily be read.

2. When working on a map or chart use a chisel point pencil and draw thin clear lines, which can be easily erased.

3. Always lay off your course, etc., as accurately as possible while on the ground before starting for the flight.

4. Take three or four pencils with you in the air, in case the point of one of them gets broken.

5. Write large plain figures which can be easily read through goggles in a dimly lit cockpit.

6. Set out clearly your track, distance, course to steer, drift, ground speed and D.R. times.

7. Do not forget to note the hour and minute of leaving the ground. Your D.R. calculations will depend for their accuracy upon this knowledge.

8. Keep a rough log of the trip and always, when you fix your position, note it down with the time of the fix, also when you alter course or change height.

9. Check your drift as often as possible.

10. Remember always the deviations of the compass: deviation east—compass least, deviation west—compass best.

11. Always carry a reliable watch.

12. The air speed is never the same as the ground speed, except in a flat calm.

13. If lost, (1) remember where your last fix was, (2) think what course you have steered since, (3) what speed you have made good, (4) note any change of drift. Fix your position on the map from these data and search the ground for landmarks.

14. Memorise the prominent features of the track you are going to steer and remember that no two railways, roads, rivers or canals exactly resemble each other.

CHAPTER X.

DEFINITIONS.

A Sphere is a solid body having a uniform round surface every point on which is equidistant from a certain point within it called the centre.

A Spheroid is a solid body the shape of which is such as would be formed by the rotation of an ellipse about its major diameter, when it is a prolate spheroid, or about its minor diameter when it is an oblate spheroid.

The Earth is an oblate spheroid, its polar diameter being 7,900 miles and its equatorial diameter 7,926 miles. For all purposes of navigation, however, it is treated as being a sphere.

The Axis of a body is that diameter about which it rotates. The Earth rotates once every 24 hours about its polar diameter, from west to east. This causes the heavens to appear to rotate from east to west.

The True or Geographical Poles of the Earth are the extremities of its axis, known as the North and South Pole, respectively.

The Magnetic Poles of the Earth do not coincide with the true poles, they are the positions on the Earth towards which an undisturbed magnetic needle will point.

A Great Circle of a sphere is such that when it is drawn round the surface its plane passes through the centre of the sphere.

A Small Circle is a circle round the surface of a sphere whose plane does not pass through its centre.

The Equator is the great circle round the Earth midway between the poles.

Meridians of Longitude are semi-great circles joining the poles. They cut the Equator at right angles. Longitude is measured in degrees on the Equator, 180° east and 180° west of the meridian passing through Greenwich, which is termed the prime meridian.

Parallels of Latitude are small circles whose planes are parallel to the Equator. Latitude is measured in degrees North and South of the Equator. 0° at the Equator and 90° at the Poles.

The position of any place on the Earth's surface can be determined by the intersection of a parallel of latitude with a meridian of longitude.

Difference of Latitude (d. Lat.) is the arc of a meridian intercepted between the parallels.

Difference of Longitude (d. Long.) is the length of the smaller arc of the Equator intercepted between two meridians.

Departure is the amount of easting or westing made in going from one place to another.

True Course is the angle between the fore-and-aft line of the craft and the true meridian.

Magnetic Course is the angle between the fore-and-aft line and the magnetic meridian.

Compass Course is the angle between the fore-and-aft line and the direction in which the compass needles are pointing.

Track Angle is the angle between the course made good and the true meridian ; it is briefly known as the track.

Drift is the angle between the fore-and-aft line of the craft and the track, and is measured relative to the craft's head, to port or starboard.

Windage is the speed and direction of the wind.

Air Speed is the speed of the craft relative to the air.

Ground Speed is the speed of the craft relative to the ground.

Run is the track and distance covered in any period of time.

Estimated or D.R. Position is the position at which the craft should arrive at any given time, calculated from the run.

A Position Line is any line drawn on a map or chart passing through the position of the Aircraft.

A Bearing is the direction of any object relative to some fixed point. A true bearing is relative to the true north, a magnetic bearing to the magnetic north, and a compass bearing to the compass north.

A Fix is the actual position of the Aircraft, determined by observation of the ground immediately below, or by the intersection of position lines.

Line of Total Force is the direction which a freely suspended magnetised needle takes up under the influence of the Earth's magnetism, varying according to the geographical position.

Magnetic Poles are the two positions on the Globe where the line of total force is vertical and towards which the needle points in all adjoining regions.

Magnetic Equator is the line separating the red and blue magnetism of the Earth, on which the line of total force is horizontal.

Magnetic Meridian is the vertical plane passing through the longitudinal axis of a magnetised needle resting in a line of total force.

Magnetic Dip or Inclination is the vertical angle contained between the directions of a freely suspended magnetised needle resting in the line of total force and the horizontal plane passing through its centre. The magnetic dip at Greenwich is about 67 degrees and the variation about 15 degrees west.

Magnetic Latitude is measured from the magnetic equator and is analogous to ordinary latitude. Lines of equal dip correspond to parallels of latitude.

Magnetic Variation is the horizontal angle contained between the directions of the magnetic and true meridians.

CHAPTER XI.

PRACTICAL AIR PILOTAGE BY PILOT FLYING SOLO.

The notes for which this chapter is written are intended primarily for the use of pupils and instructors at Schools of Air Pilotage and for the general assistance of pupils and observers making long flights over country devoid of landmarks or undertaking overseas flights of even moderate length. In all long flights where the aircraft is carrying a trained observer the methods laid down in the preceding chapters should be carefully followed and the craft should accordingly be piloted with relatively scientific accuracy. But when a pilot undertakes a cross country flight without the assistance of an observer the principles laid down in these notes require some modification to suit the conditions under which the pilot has to work. It is realised, for example, that it is extremely difficult for the pilot, flying by himself, to use such instruments as the drift indicator which is primarily designed for accurate air pilotage when an observer is available.

Nevertheless, no pilot can expect to fly across country or over seas with any degree of accuracy or success unless he has a thorough understanding of the principles upon which the various air pilotage instruments are designed, and he should also make himself well acquainted with the chapters devoted to Map Reading, the Magnetic Compass and the Adjustment of the Compass, and should be familiar with the method of working out the course, from given data, on the ground.

Provided he has mastered the general theory of cross country flying and has a thorough knowledge of his compass and of his map, a pilot should be able, with the intelligent use of certain simple aids which are described below, to find his way by air over land or over sea under the most indifferent weather conditions.

An endeavour is made in this chapter to describe how a pilot should conduct a long cross country flight, and for this purpose a representative example of a practical cross country flight is described below.

We will suppose that a pilot has received orders to fly from his aerodrome A to a destination B, distant 200 miles, and that the journey is to be undertaken in a Bristol Fighter. Instructions for the flight should be entered on a Route Card and handed to the pilot, whose first preoccupation should be to see that his aeroplane is in all respects fit for the journey.

If the aeroplane is one which he has not previously flown he should take the first opportunity to test her in the air. During this test flight, in addition to noting any small points requiring attention—such as the addition of an extra cushion in his seat or the adjustment of the ballast to improve the fore and aft balance, he should be most careful to check the behaviour of his compass. There is nothing more embarrasing to the cross country flyer than uncertainty with regard to the accuracy of his compass after commencing his flight. This uncertainty is liable to increase as the flight proceeds and often leads to failure on that account alone.

If this trial flight takes place on the day for which the long flight is ordered the pilot should take the opportunity of checking the drift and compass course in accordance with the principles laid down in Chap. VIII.

We will now suppose that he has returned to the aerodrome, has seen that his tanks are filled to their full capacity, has entered the data for the flight on his Route Card, and has marked his course clearly on his map. In this connection he should take particular care to pick out suitable conspicuous landmarks on his course and to tabulate the D.R. time which he estimates it will take to reach each of them. In regard to this choice of landmarks, the best are undoubtedly railways running at right angles to his course; also large towns, lakes, rivers and forests. The last two should be picked with a certain amount of discrimination, a small stream, for example, may easily be passed unnoticed especially in bad visibility, while the value of a forest as a landmark will depend upon the nature of the surrounding country. In open country such as is met with in France, however, large woods are good landmarks, while main roads may also be added to the list given above.

The pilot now sets off on his flight, being very careful to note the time of departure, and as soon as he sets his aeroplane upon her course he should impress upon his mind by observing smoke, bunting, etc., the direction in which the ground wind is blowing and its relative strength, so that later on in the flight, on repeating these observations, he may be in a position to estimate any change in the direction or strength of the wind. In this connection the best rough indication of the speed and direction of the wind is given, on a sunny day when the sky is partly covered with broken clouds, by the ground shadows of the clouds from which he can obtain a good indication of the direction and speed of the upper wind. It may be necessary to explain that, although the pilot has already entered all details regarding the wind on his route card, the object of making these observations is to provide a mechanical check which may enable him to compare his impressions from similar observations later in the flight. Meanwhile, the pilot should be checking his progress by the map and should keep correcting his course until his track coincides with the course which he has marked out for himself on the map, and should take a very careful note of the compass bearing upon which he is then flying. He should keep his aircraft to this compass bearing throughout the flight unless he sees good reason to change it.

Now there is no difficulty whatever in carrying out the flight to a successful conclusion providing the visibility remains good and the ground over which he flies is provided with abundant landmarks which he can compare with the map; but we will suppose that after flying for half-an-hour the visibility deteriorates rapidly and a thick misty drizzle sets in. The pilot may now find himself flying over a country which he can only see directly below him and of which the ground features are not of a distinctive nature. He may be driven to fly lower and lower to keep below the clouds and he finds that it becomes more and more necessary to concentrate his attention on flying his aeroplane and on keeping the compass course. He can no longer rely upon recognising his course by comparing the ground with the map, a process which becomes slow and laborious. He must therefore concentrate entirely upon flying a correct compass course in accordance with his preliminary calculations, modified if necessary to allow for the difference in his altitude.

It is under these conditions that the pilot must rely practically entirely upon his compass and upon the accuracy of his calculations, but he will still have one most important check, the value of which will depend upon the nature of the landmarks which he has selected, and to reach which he has calculated the D.R. times. As these become due he should look out for them very carefully and as he passes them check the time at which he reaches them with the time originally estimated.

It is possible that the visibility is so bad or the principal landmarks chosen by him so inconspicuous that he may pass them unobserved. This need not, however, seriously disturb him, and he should continue his flight making every endeavour to check the direction and speed of the wind, noting any change which may have occurred since he commenced the flight and making any small adjustment to his course which would appear to be necessary on this account. So he may continue on his course until he calculates that he must be approaching his destination, and if he has still failed to pick up landmarks it is then time to take serious steps to locate his position. He therefore looks at his watch, and we will suppose that he finds that he has been flying for an hour and 40 minutes and that he has originally calculated that his speed would be 90 miles an hour and has seen no reason to change that estimate. He should locate his D.R. position on the map as rapidly as possible by means of the appropriate scale provided on the edge of the Route Card, and then, by observation of the ground wind and by noting the direction of his drift, he should try to estimate any probable error in his D.R. reckoning. Having fixed his new D.R. position to the best of his ability by these means he should now watch the ground very carefully while continuing on his course and pick a suitably conspicuous landmark—in England either a river or a railway. Let us suppose it is a railway ; his first step is to note the direction in which it runs, and looking at his map he picks a similarly oriented railway in the neighbourhood of his D.R. position. He may assume, at once, that he has picked the right one, but it is most advisable that he should obtain some confirmation. He therefore notes from his map any particular characteristics which may enable him to indentify his railway, for example—supposing the railway to run north-west and south-east—he may note that it bifurcates a few miles to the north-west of the point at which he thinks he has struck it, or that it crosses a river, or runs through a large wood. To confirm his position, therefore, he should follow his railway to the north-west in order to find these identification marks. If he does not find them, one of two things may have happened ; either he has picked the wrong railway from his map or he has struck the railway at a point other than he has estimated. He knows, however, that he is unlikely to be very far from his D.R. position and with the aid of any conspicuous characteristic which he can observe on the railway (a bridge over a river, for example) he should, by studying his map, soon be able to identify his position.

This he may expect to do by a process of elimination somewhat as follows : His D.R. position is at least an indication of the district in which he may expect to be and he should fold his map so that he can examine an area 20 to 25 miles square, of which his estimated D.R. position is the centre. He may observe that there are three railways in that area all of which correspond in direction to the one he has found, only two of them, however, cross a river. He should therefore be on one or other of these, and has only to multiply his identification marks to determine his actual position.

Although this may appear to be a somewhat lengthy and elaborate process it is, in actual fact, very simple and, provided the pilot can use his map quickly and intelligently, should enable him to locate himself in a very few mintues. Should he fail to do so he can only assume that he must be some way off his course and that the railway he has struck is further from his estimated D.R. position than he expected.

In such a case the pilot is for the moment definitely lost and can only locate himself by overhauling his D.R. data with a view to determining in what direction he should expect to be relative to his estimated D.R.

position. With this object in view he should, while circling within sight of the landmark which he wishes to identify, endeavour to answer the following questions :—

(i) Does the wind appear to have changed ?

(ii) If so, how would it have affected my course and speed ?

(iii) During the flight have I altered my course to avoid clouds, etc. ? In what direction have I altered it and approximately for how long ?

(iv) Have I changed my elevation and therefore encountered an altered effect from the wind ?

(v) Have I altered the speed of my aircraft by opening full up or throttling down ?

(vi) In what direction was I drifting when I started and in what direction am I drifting now ?

In a dilemma of this kind the pilot's main difficulty is to calculate the effect of any change of wind or to ascertain if there has been a change. By employing the drift indicator this problem is easily solved, since a check on the drift of the aircraft will at once be a guide as to how much off the original course he has flown. But the pilot flying alone must rely upon more rudimentary methods of locating himself once he is lost; but, provided he has kept his wits about him during the flight, has checked the D.R. times properly, knows the error of his compass and has kept the compass course carefully, he should never be so far from his D.R. position as to be unable to locate himself by the intelligent examination of a railway, town or river, and by applying the eliminating process described above. He will be assisted very considerably if he is able to determine the direction of his drift even roughly and so compare that direction with the similar observations which he made at the commencement of his flight. A device designed to aid the solo flying pilot in the determination of his drift is already being experimented with. This device which consists of lines painted on the top of the lower planes near the fuselage, is really a form of rudimentary drift indicator from which approximate results can be obtained by a pilot without the necessity of leaning far from his seat. It may be confidently affirmed that no pilot will lose himself even in the worst of weather—always excepting a thick and extensive fog which prevents any view of the ground—provided that he has taken proper precautions before and at the commencement of the flight. Once a pilot finds himself in difficulties it is too late to regret the fact that he forgot to take the time of leaving the aerodrome or that he had never ascertained the error of his compass, or the original direction of his drift.

Should a pilot be definitely lost he still has the following final resorts :—

(i) If he has sufficient petrol he may be able to fly to find some unmistakable landmark by which he may locate himself, such as, for example, the Thames or the coast line.

(ii) If unable to do this he may, if he is a good pilot with plenty of confidence, fly low down and read the name of a railway station ; a dangerous remedy.

(iii) Finally, his last resort would be to land and enquire. Even this conviction of failure may result in a disaster unless the pilot acts with considerable discretion. It is strange how often an aeroplane is wrecked by a pilot endeavouring to land to ask his way. There should be no excuse for this since he still has full use of his engines and can fly about quite low down until he has selected a suitable landing ground and convinced himself that it is, in all respects, satisfactory.

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